Technology-Based Formative Assessments: Student Perceptions in Pre-Calculus Mathematics

by

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ABSTRACT

Formative assessment was pushed to the forefront of educational discussion in Black and Wiliam's *Inside the Black Box* (1998b) and continues to be an integral part of assessment in the classroom. The National Council of Teachers of Mathematics (NCTM) (2014) suggested both formative assessment and technology must be indispensable features of the mathematics classroom for meaningful learning to occur. This study examined these two features combined together in technology-based formative assessments. Specifically, this study explored the experiences of students with Google Forms and Desmos as technology-based formative assessments. The purpose of this study was to give voice to the students and to explore the commonalities that existed in their experiences and to see if their experiences aligned with Wiliam and Thompson's (2007) five key strategies of formative assessment. Six former students were interviewed in this qualitative research study. Three themes emerged from the data; the students expressed that the technology-based formative assessments gave them an opportunity to take a personal check-in of their understanding, gave them the opportunity to be engaged as owners of their own learning and allowed them to experience interactive and engaging activities, something other than yet another worksheet. A variety of minor themes and unique responses also emerged from the data. Five key elements related to the affordance that technology specifically allows for in these formative assessments is also discussed. The findings of this study provide researchers and educators with the important opportunity to hear from the students and to use their experiences to create more meaningful technology-based formative assessments for future students.

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Chapter 1: Introduction of Thesis Topic

Background

When I began my mathematics teaching career twelve years ago, my classroom modelled the traditional mathematics classroom I had experienced in my years of high school and university mathematics. I, as the teacher, was the expert mathematician and the students were the eager vessels ready to be filled with my knowledge of the wonder and beauty of mathematics. I planned for monthly tests and bi-weekly quizzes to gauge the fullness of these vessels and to prepare them for the impending midterm and final exams. As my classroom experiences accumulated, I became frustrated with having very little idea of my students' understanding and misconceptions until these high-stakes summative assessments. Students who completed their homework and seemed to grasp the topics during lectures, often struggled on assessments. Not only was this a surprise to me as their teacher, but it seemed to surprise some students as well. By the time the graded tests had been returned to the students, we had moved on to a new topic and the opportunity to address any issues while they could still affect student understanding felt like it had passed. As a new teacher, I did not have any solutions from my limited experience as an educator and since I was recreating my own mathematics classroom experience, I had no other classrooms to model.

Fortunately, at this time Twitter had become a gathering place for educators to share ideas about teaching, as well as blogs and articles about effective teaching. These educators began reforming my understanding about teaching and learning mathematics. Students were no longer empty vessels but equal partners in the classroom with complex mathematics backgrounds and interesting perspectives on using different methods to solve problems. The student's voice suddenly had a place in my classroom and continued to shift my perspective on effective methods of teaching mathematics.

To extend these ideas and connect them with the current research, I began a Master of Education program and was introduced to Hattie's *Visible learning for teachers: Maximizing impact on learning* (2011). While working through Hattie's research, formative assessment, as one of the major influences on student learning emphasized by Hattie, resonated with me. I was particularly intrigued by the definition of formative assessment referenced by Hattie:

> Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited. (Black & Wiliam, 2009, p. 9).

Formative assessment was the key to getting student insights earlier in the process when adjustments could be made to my teaching. I was now about to see student misconceptions while they could still be addressed, as well as gain insights into connections and solutions I did not see before. My initial use of formative assessment was limited to pen and paper entrance/exit slips, which were effective but time-consuming practices to get a sense of my students' understanding. Black and Wiliam (2009, p. 9) suggest that "formative assessment is concerned with the creation of, and capitalization upon, 'moments of contingency' in instruction for the purpose of the regulation of learning processes". I realized that taking advantage of these moments of contingency almost immediately during class could be a powerful tool. I began to experiment with different technology-based formative assessments, which would allow me to quickly gauge the level of understanding at a class level and respond in a timely fashion to take advantage of these moments of contingency almost immediately.

Context of the Study

My search for technology-based formative assessment tools led me to many different Web 2.0 sites, but I settled on Google Forms and Desmos for Pre-Calculus 30S and 40S classes (Manitoba Education and Advanced Learning, 2014). These courses are "designed for students who intend to study calculus and related mathematics as part of post-secondary education" (Manitoba Education and Advanced Learning, 2014, p. 139). I began teaching Pre-Calculus 30S in my first year teaching, so by the time I started to use technology-based formative assessments I had over ten years of experience with the course. Pre-Calculus 40S was added to my teaching load two years ago, but followed much the same rhythm and style as Pre-Calculus 30S. This allowed me to understand the ebb and flow of both courses; the areas of difficulty and the areas where students needed additional experiences with the material to conceptualize the topic.

I used Google Forms as an electronic entrance/exit slip, often with multiple-choice questions and opportunities for students to share where they felt they needed more support. The multiple-choice questions were auto-marked with the scores shared immediately with students. Questions where the class in general struggled were highlighted on the teacher dashboard. Upon reflection, I was using Google Forms as a faster, more immediate and efficient version of the entrance/exit ticket I had been using in previous years.

I began to use Desmos in a similar way as Google Forms, however as the website itself grew in scope, I began to realize how powerful it could be in previewing material, supplementing the learning of new material, and assessing the students' knowledge of the material. Students could work through activities while having their responses recorded and viewed on the teacher dashboard, and as the teacher, I could highlight student responses in an unobtrusive and anonymous way. At this point, I felt that I had leveraged formative assessment to its fullest extent in my classroom.

As both Desmos and Google Forms added features that increased their formative assessment scope and with my own research into formative assessment, I began to realize I had missed an integral part of formative assessment. From Black and Wiliam's (2009) initial definition quoted by Hattie (2011), I had elicited and interpreted the student achievement to inform my teaching decisions, but completely missed the mark on the learners and their peers using the data to better inform their learning decisions. This became even more clear when reading the final three strategies of Wiliam and Thompson's (2007) five key strategies of formative assessment:

1. Clarifying, sharing, and understanding goals for learning and criteria for success with learners.
2. Engineering effective classrooms discussions, questions, activities, and tasks that elicit evidence of student's learning.
3. Providing feedback that moves learning forward.
4. Activating students as owners of their own learning.
5. Activating students as learning resources for one another.

I had never understood the two-pronged nature of formative assessment until reading these strategies. I experienced the benefits from the evidence obtained by formative assessment to make decisions about my instruction, but neglected that students and their peers could also use this information to better inform their next steps in their learning. Although I believed technology-based formative assessments had positively contributed to my pedagogical decision making as the first two strategies suggested, I realized that I could not say for certain that my students' experiences had been as powerful.

Purpose of this Study

In my experience as a high school mathematics teacher, I have seen many of the previously mentioned benefits of formative assessment and specifically, technology-based formative assessment first hand. In particular, the ability to gain insight into a student's reasoning in real time has helped to reshape the way I approach much of the material in the curriculum. Much of this reshaping has come from my own perspective of the effectiveness of the lesson and not the students' experience of these assessments. Just as I had missed encouraging the students to use the formative assessment data to inform their learning, the students' perceptions of if and how technology-based formative assessments contribute to their own learning should be an integral part of being able to call these assessments a success or a failure. Therefore, the purpose of this study was to gain an in-depth understanding of the experiences of students who complete technology-based formative assessments to better understand their learning experience. First and foremost, the study is intended to gather insights into whether my students feel that there are any benefits to their own learning from these assessments. Their insight will contribute to future iterations of these assessments, enabling me to create more meaningful assessments from the weaknesses they identify. Second, I believe from my own experience that students are often forgotten as instructional decision makers, which is an important pillar of formative assessment (Stiggins, 2005). As such, this study contributes to giving my students a voice as an important part of the formative assessment process.

Methodology and Research Questions

In order to give my students a voice in this process, a phenomenological design inspired the qualitative research method that was chosen as it best allowed me to explore and detail the experiences of my former students. An interview protocol with open-ended questions (Appendix A) was used to conduct interviews with six former students who have completed either a Pre-Calculus 30S or 40S and have since graduated from the school. As these students completed a Pre-Calculus course with me as their teacher, and in order to avoid the ethical concerns of a power over situation, these interviews took place after the students graduated from the school and on a voluntary basis. The interviews were transcribed and coded using concept coding (Saldaña, 2016).

The central question which framed my research was: What is the experience of senior high school mathematics students who participate in technology-based formative assessments? Specifically, the four questions that guided this research were:

1. What are Pre-Calculus 30S and 40S students' reflections on how technology-based formative assessments have affected their learning?
2. What are the commonalities in these student's experiences?
3. How do the experiences of these students relate to Wiliam and Thompson's (2007) five key strategies of formative assessment?
4. What implications might these students' reflections have for how I approach technology-based formative assessments?

Significance of Research

There has been a call for teachers and researchers to explore ways "technology can support and promote… classroom-based assessment (formative and summative)" (Looney, 2011, p. 30). By collecting and analyzing student reflections on their experiences with technology-based formative assessment, I believe this study gives both researchers and teachers insight into the students' perspectives about how the use of these assessments in the high school mathematics classroom affects their learning. Much of the research on technology-based formative assessment has focused on the experiences of classroom teachers (Lee, Feldman, & Beatty, 2012; McKnight et al., 2016; Pachler, Daly, Mor, & Mellar, 2010; Roschelle et al., 2010; Shirley & Irving, 2015; Suurtamm, Koch, & Arden, 2010), but there has been limited research examining student perspectives on formative assessment (Hattie & Gan, 2011).

It is my belief that a gap also exists in the research concerning technology-based formative assessments in the high school mathematics classroom, as much of the existing research surrounding technology-based formative assessment focuses on the effectiveness of proprietary or hardware based formative assessment technology such as TechPALS in early years (Roschelle et al., 2010) or web-based media player Transformative Anchored Collaboration Environment (TrACE) at a post-secondary level (Schroeder & Dorn, 2016). Desmos and Google Forms are relatively new websites that are constantly evolving and I believe this study contributes to a new research base of technology-based formative assessments in the high school mathematics classroom. Stödberg (2012) specifically mentions the lack of research on how students experience various forms of electronic assessment (e-assessments) and how they use these assessments to support their own learning. The data from this study contributes to the development of new technology-based formative assessments and further development of the current tools.

Although much of what is presented in this study surrounds the feedback received by the technology based formative assessments and the student perceptions of the feedback, it is important to mention that feedback is just one step of formative assessment. “Feedback is formative only if the information fed back to the learner is used by the learner in improving performance” (Wiliam, 2007, p. 1075). The feedback provided by the technology-based formative assessments was used by both the students and me, the teacher, to take steps to further learning. The students used this feedback to seek extra help opportunities from each other and from me, as well as using the online resources provided in the class. I used the feedback to make decisions at the whole class level, deciding whether to review the previous day’s material or to proceed with a new topic, as well as with the individual students, touching base to see what they needed to reinforce their understanding.

Finally, this study gave me insight into my own student’s experiences with my deployment of technology-based formative assessments. As previously mentioned, I have seen the benefits from a teacher’s perspective but have neglected a formal investigation into the students’ views. Since student success “rests, at least in part, on what students do with and about” (Stiggins, 2005) the results on assessments, it is my belief that gathering their feedback on how these assessments affected their learning is integral to creating better assessment in the future. I plan to use their experiences to improve my implementation of future assessments and activities in the classroom.

Summary

My journey to my current practice and understanding of technology-based formative assessments in the mathematics classroom has grown over the entirety of my teaching career. Just as I missed giving students a voice in my own classroom, I believe students have also been missed as integral parts of the analysis of technology-based formative assessment research. Although this study only focused on the experiences of a few students at a single school, I believe their perspective can contribute to the research needed to begin to fully understand the effects of technology-based formative assessment in the mathematics classroom.

Chapter 2: Review of Literature

This literature review provides an overview of the research related to technology-based formative assessment in the mathematics classroom. Due to the specific nature of this study, the literature has been broken down into three sections. The first section will discuss the major studies and contributions to formative assessment in general, followed by an examination of formative assessment in the mathematics classroom. The final section will outline common themes across formative assessment, mathematics and technology that connect to technology-based formative assessments in the mathematics classroom.

Section I: Formative Assessment – A Poverty of Practice

More than fifty years ago, Scriven (1967) first introduced the distinction between formative and summative when discussing program evaluation in education (Bennet, 2011). According to Scriven, formative evaluation was a rational part of producing good results on summative evaluations. Since that initial distinction a half century ago, the terms formative and summative have been applied to types of student assessments (Bloom, Hastings, & Madaus, 1971), yet summative assessments continue to be the more common of the two (Heritage, 2007). Formative assessment, although pushed to the forefront of educational discussion in Black and Wiliam's *Inside the Black Box* (1998b) and central in the assessment policies of many Canadian Provinces (Manitoba Education, 2006; Ontario Ministry of Education, 2010), is often not fully implemented in classrooms even though the benefits read as the solution to many of education's problems. From giving teachers information about students' learning at a point where adjustments to instruction can be made (Beckett, Volante, & Drake, 2016) to being indivisible from teaching and reducing the range of achievement in a class while raising the overall achievement (Black & Wiliam, 1998b), one may question why there continues to be a poverty of formative assessment practice in classrooms. Many have proposed reasons for this research practice divide, with teachers, teacher educators and school divisions all sharing in the blame (Beckett et al., 2016; Black & Wiliam, 1998b; Stiggins, 2005). A common theme that emerges is the difficulty in defining formative assessment more precisely. To attempt do so, I will first examine some of the theoretical backgrounds for formative assessment in the literature.

Origins and theory prior to *Inside the Black Box.*

As previously mentioned, after Scriven's (1967) initial distinction, Bloom, Hastings, and Madaus (1971) applied the formative and summative differentiation to assessments. Bloom et al. referred to summative assessments as the assessments administered after the learning had taken place (sometimes referred to as assessments of learning). In contrast, formative assessments or assessments for learning, were to help students pace their learning and ensure learning task mastery. As I attempted to further situate these initial definitions in theory, I found that some researchers believe that formative assessment is not specifically associated with any theory of learning (Wiliam, 2010). However, many current conceptualizations do have roots in a sociocultural constructivist view of learning (Heritage, 2010; Wiliam, 2010), "borrowing from cognitive, constructivist, and sociocultural theories" (Shepard, 2000). Under this view, learning is an internalization of social activity where students develop knowledge and understanding over time, mediated by others with greater expertise (Vygotsky, 1978). To better understand how students develop understanding, Vygotsky proposed the zone of proximal development (ZPD), or

> "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (p. 86).

In his paper on feedback, which is a key element in formative assessment (Sadler, 1989), Ramaprasad (1983) relates this gap (or ZPD) to feedback, stating that "feedback is information about the gap between the actual level and the reference level" (p. 4). Sadler (1989) builds on this definition of feedback to develop his proposed theory of formative assessment, once again circling back to the importance of Vygotsky's ZPD and Ramaprasad's definition of feedback. Feedback is only considered as such when it is "used to alter the gap" (Sadler, 1989, p. 121) and for this feedback to be formative assessment, it must

a. possess a concept of the standard (or goal, or reference level)
b. compare the actual (or current) level of performance with the standard
c. engage in the appropriate action which leads to some closure of the gap (Sadler, 1989, p. 121)

Feedback and therefore formative assessments, can help to identify the optimum gap between a learner's current status and the aspiration so as to encourage the learner through the learning process. It is important to make note that with both Vygotsky's ZPD and Sadler's theory of formative assessment, adult guidance, peer guidance and self-assessment are all stressed, which in my opinion further reinforces the importance of gathering students' perspectives on whether technology-based formative assessments do provide these opportunities.

The development of a definition.

Black & Wiliam's (1998b) research review of over 580 articles and chapters thrust a spotlight on formative assessment and its impact on student learning with both their research paper and their accompanying position piece. This spotlight partially originated from the finding of effective sizes in formative assessment experiments between 0.4 and 0.7, larger than those found with most other educational interventions (Black & Wiliam, 1998a) and in effect doubling average growth students would be expected to make on standardized tests in a school year. These findings were reiterated in the meta-analysis studies of Hattie (2011). Using this research review as a starting point, Black and Wiliam continued with their own research, working with mathematics and English teachers to find five main types of formative assessment activity: sharing success criteria with learners, classroom questioning, comment-only marking, peer and self-assessment and formative use of summative tests (Black, Harrison, Marshall, & Wiliam, 2003; Wiliam, 2007). To provide a better theoretical grounding for formative assessment, Wiliam and Thompson (2007) combined these activities with Ramaprasad's (1983) three key processes in learning and teaching: establishing where the learners are in their learning, establishing where they are going and establishing what needs to be done to get them there to produce the framework shown in figure 1.

	Where the learner is going	Where the learner is right now	How to get there
Teacher	**1** Clarifying learning intentions and criteria for success	**2** Engineering effective class-room discussions and other learning tasks that elicit evidence of student understanding	**3** Providing feedback that moves learners forward
Peer	Understanding and sharing learning intentions and criteria for success	**4** Activating students as instructional resources for one another	
Learner	Understanding learning intentions and criteria for success	**5** Activating students as the owners of their own learning	

Figure 1. Aspects of formative assessment (Wiliam & Thompson, 2007)

As shown in Figure 1, formative assessment can be conceptualized in the five key strategies, once again emphasizing the importance given to both the teacher and the student in the process of formative assessment.

Formative assessment definition.

With this framework and theoretical background in mind, I restate the definition included in Chapter 1 to further elaborate on a few points.

> Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited. (Black & Wiliam, 2009, p. 9).

While attempting to develop their theory of formative assessment, Black and Wiliam (2009) first specify that instruction "refers to any activity that is intended to create learning" (p. 7) and that the decisions may not always result in better learning for all students. In my opinion, this definition best captures the strength and struggle that is found in formative assessment. All agents (students, peers and teacher) must be active participants in the activity to see the full benefit, yet there is still the risk that one (or all) of the agents may not make the best possible decision based on their analysis of the situation. This definition also helps to identify the major difference between feedback and formative assessment. Feedback is a necessary step of formative assessment, but "feedback is formative only if the information fed back to the learner is used by the learner in improving performance" (Wiliam, 2007, p. 1075). In my opinion, when the feedback is used to inform the decisions that both teachers and students make about learning going forward it becomes part of the process of formative assessment as seen the figure 1.

A number of important points are raised in *The Handbook for Embedded Formative Assessment : (a Practical Guide to Formative Assessment in the Classroom)* (2018), which accompanies Wiliam's book *Embedded Formative Assessment*, about Black and Wiliam's definition for formative assessment. It reinforces that leaners and their peers, along with the teacher, are agents in making decisions and that the decisions and actions that take place are more important than the intent. That is, if there is intention to use the information, but no action takes place, then the assessment is not formative. Finally, the document recognizes that learning is too unpredictable to ever guarantee learning will take place. Black and Wiliam's definition allows for this, stating that the decisions are "likely to be better", which allows for the possibility that even the best intentioned or designed interventions will not always guarantee better learning for all students.

One final note on this definition; it makes it clear that formative assessment is "concerned with the creation of, and capitalization upon, 'moments of contingency'" (Black & Wiliam, 2009, p. 8). These moments of contingency are moments that arise during teaching and learning where both students and teachers can use information gathered about learning and use it to make adjustments. These can be synchronous, such as using a Google Form auto-marking quiz for students and teachers to make real time adjustments during the lesson, or asynchronous, such as a teacher using the information from exit slips or homework to prepare for the next class. This idea of a synchronous moment of contingency also lead me to the use of technology-based formative assessments, as they allowed for instantaneous feedback for both myself and my students.

Although Black and Wiliam are not the only authors of a model or framework of formative assessment (Bell & Cowie, 1999; Heritage, 2010), they have attempted to theoretically ground their framework in various learning theories and acknowledge that it is an *attempt* (Black & Wiliam, 2009). Much of Wiliam's work concentrates on formative assessment in the mathematics classroom (Black et al., 2003; Wiliam, 2007) which is relevant for this particular study and as such, I have used their work extensively in this literature review. Their work is not without detractors though and Bennett's (2011) position paper attacks the report of effect sizes between 0.4 and 0.7 for formative assessment. Bennett believes that Black and Wiliam's review and meta-analysis (1998a) is too disparate to make meaningful claims and questions the validity and efficacy of multiple formative assessment studies. After considerable text is spent on these issues, Bennett concludes that formative assessment is "both conceptually and practically still a work-in-progress. The fact means we need to be more sensible in our claims about it, as well as in our expectations for it. The fact also means we must continue the hard work needed to realize its considerable promise." (2011, p. 21). Although Bennett disagrees with the effect sizes found by Black & Wiliam, he does agree with the considerable benefits of formative assessment. As with all research, there is a need to be cautious in claims and contribute to the research base with further studies. His conclusion is one that I completely support and another reason why I believe studies like this can contribute to the research base for this topic.

Section II: Mathematics and Formative Assessment

At first glance, much of the research on mathematics assessment focuses on the formal summative assessments, particularly tests and examinations, with these assessments being the primary source of determining student's knowledge (Wiliam, 2007). As such, there has been a call for reform of the mathematics classroom as well as research regarding assessment in the classroom (Beckett et al., 2016; Suurtamm et al., 2010; Wiliam, 2007). The NCTM (2014) states six guiding principles for school mathematics: teaching and learning, access and equity, curriculum, tools and technology, assessment and professionalism. Specifically, assessment in "an excellent mathematics program ... includes a variety of strategies and data sources, and informs feedback to students, instructional decisions, and program improvement" (NCTM, 2014,

p. 5). As one of the six guiding principles, assessment holds an important place in the mathematics classroom. Although assessment includes both summative and formative assessment, the National Math Advisory Panel (NMAP) specifically recommends regular use of formative assessment in the classroom and that its regular use will improve student learning (NMAP, 2008). As previously discussed, there are many benefits to formative assessment for both students and teachers of all subjects. This section will examine some of the reasons for the use of formative assessment in the mathematics classroom.

Mathematics teachers who put a greater emphasis on formative assessment have been shown to make more effective use of their instructional time (NMAP, 2008) which, in turn, has been argued to be the most effective test-preparation strategy (NCTM, 2014). In my opinion, this connects back to Black and Wiliam's claim of formative assessment being indivisible from effective instruction (1998b). Even in an education world where high stakes summative assessments are used to evaluate students, teachers and schools, formative assessment can be used in the mathematics classroom while still conforming and succeeding with the mandated summative assessments. According to Wiliam, "in other words, even if teachers do not care about deep understanding and wish only to increase their students' test scores, then attention to formative assessment appears to be one of, if not the, most powerful way to do this" (2007, p. 1091).

The mathematics teacher has to maintain a delicate balance of a student's mathematical content knowledge, mathematical processes (reasoning, communicating, making connections), and mathematical disposition (attitudes, persistence, confidence, and cooperative skills) (McIntosh, 1997). Formative assessment, whether through interviews, journals, surveys or exit slips, can provide insight into these three domains, insight which may otherwise not have been possible (McIntosh, 1997; Wiliam, 2007). This variety of assessment activities engages students to connect mathematical ideas, connect with other students in discourse and make sense of mathematical claims which is integral in helping teachers assess the range of mathematical activity in their class (Suurtamm & Koch, 2014). In short, formative assessment can give teachers a variety of methods for students to show their progress in each of these three domains.

Perhaps as important as giving the teacher insight into these domains is the fact that formative assessment can activate students as owners of their own learning (Wiliam, 2007) and can give them insight into the three previously mentioned domains for their own purposes. Formative assessments can make students self-assessors of their own understanding (NCTM, 2014) and can encourage them to compare their own work with others, which is a considerable benefit for students who do not find mathematics easy to learn (NCTM, 2014; Wiliam, 2007). Although not based on the mathematics classroom, Clark (2012) investigates this idea of making students self-assessors of their own understanding, connecting formative assessment with the concept of self-regulated learning (SRL) through an analysis of the theory behind formative assessment and self-regulated learning. Formative assessment is “designed to continuously support teaching and learning by emphasizing the meta-cognitive skills and learning contexts required for SRL; planning, monitoring and a critical yet non-judgmental reflection on learning, which both students and teachers use collaboratively to guide further learning and improve performance outcomes” (Clark, 2012, p. 217). Not only do these meta-cognition skills help students to learn in a mathematics classroom, they also can help students actualize the drive for life-long learning (Clark, 2012). A word of caution at this point, although these findings and claims are research based, they may seem to be the easy solution to all of the problems in the mathematics classroom. To see these benefits, a considerable reform in both assessment practices and classroom culture must occur, which is discussed below.

In their analysis of classroom assessment reform and mathematics education reform, Suurtamm et al. (2010) used an analysis of the curriculum as well as interviews, questionnaires and case studies to give context to assessment in the Canadian (Ontario) mathematics classroom for Grades 7 to 10. Their findings show that many teachers do have practices that support these reforms, with teachers using a variety of assessments seamlessly during instruction in order to support student learning. But this study also provided some supports that are necessary to help teachers implement these new assessment ideas. First, collaborative professional development helped teachers to network and build resources for their classrooms. Second, these teachers must also receive consistent messages from resources, curriculum documents and from professional development initiatives to realize the full potential of these reformed assessments. This suggestion is mirrored in research from Beckett et al. (2016) and, as previously mentioned, that teachers need to be supported in their quest to reform their assessment practices.

In conclusion, the reform of assessment in the mathematics classroom have been shown to produce better results on summative assessments and give teachers better insight into their students learning and understanding. One of the observations in my review of the mathematics formative assessment research is the limited amount of research examining the student perspective on these new technology-based formative assessment activities.

Section III: Formative Assessment, Technology and Mathematics

In this section, I will examine research studies that cover formative assessment, technology and mathematics, although as was previously mentioned, there are few studies which cover all three in the high school mathematics classroom. Therefore, I present studies that cover differing combinations of these three topics below.

Just as assessment is one of the six guiding principles for mathematics, technology is also highlighted as one of these principles. In fact, the NCTM (2014) suggested that tools and technology must be indispensable features of the mathematics classroom for meaningful learning to occur. In particular, technology and tools can support interactions between teacher and student and students and their peers. Although the chapter focusing on technology and tools only briefly touched on technology-based formative assessment, in my opinion, many of the benefits of technology can be extended to technology-based formative assessment. For example, technology can be used to help students make sense of a topic, engage in mathematical reasoning and communicate mathematically (NCTM, 2014). In my opinion, these technology benefits compliment Wiliam and Thompson's (2007) five key strategies of formative assessment, providing an opportunity for the teacher to see evidence of student learning when technology is used with formative assessment. A second example of this connection is how technology can allow students to investigate ideas that might be too difficult or time-consuming to explore otherwise (NCTM, 2014). This technology allows students to perform repeated calculations at a much faster rate, allowing students to engage in 'what if' explorations that would not be possible in the time constraints of class time otherwise.

> Computers, tablets, smartphones, and advanced calculators all make available a range of applications that support students in exploring mathematics as well as in making sense of concepts and procedures and engaging in mathematical reasoning. Graphing applications can allow students to examine multiple representations of functions and data by generating graphs, tables, and symbolic expressions that are dynamically linked.

> Spreadsheet applications can quickly display the results of repeated calculations and generate tables of values using a variety of graphical representations, with both of these applications allowing students to develop insights into mathematical structures and relationships. (NCTM, 2014, p. 78)

From my own experience, I would extend this concept to technology-based formative assessments as well, as these activities can also allow the teacher to immediately see how students are working through these investigations which would not have been possible without the use of technology. Although not mentioned in NCTM (2014), the NMAP specifically addressed technology-based formative assessment in their report. NMAP (2008) found the "promising" strategy of technology-based formative assessment can more effectively provide information to teachers on content or concepts requiring additional work for the whole class as well as individual students.

Although Stodberg's (2012) research review of 76 articles from three journals on e-assessment use focuses on higher education studies, I believe his noted trend and conclusion are applicable for technology-based formative assessment in the high school mathematics classroom. Although there has been an increase in research on electronic assessments (e-assessments), which address both formative and summative assessments, less than half of the 76 studies specifically focused on formative assessment. E-assessments include a wide range of assessments designed, disseminated and completed using technology (Azevedo & Azevedo, 2019), with one possible use being technology-based formative assessments. According to Stodberg, with the broad implementation of standardized assessments teachers have found it more difficult to make changes to assessments in their classrooms and even when encouraged to do so, teachers found it difficult to introduce e-assessments successfully. Although self admittedly narrow in scope, Stodberg found a lack of research on how students experience various forms of e-assessment and how they use it to support their own learning, a gap I believe this research study can begin to address.

In the cases of post-secondary formative e-assessment presented by Pachler et al. (2010), two key points stood out in their findings. First, the technology itself does not create moments of contingency, these are dependent on both the teachers' and learners' actions. Second, formative e-assessment is incredibly complex and requires a delicate balance of social, pedagogical and technological systems. These are characteristics that I kept in mind as I engaged in this study.

In the paper examining assessment cases from many different contexts, Pellegrino and Quellmalz (2010) found that teachers noticed many students have similar pre-conceptions and properly designed technology-based formative assessments can identify these to both the student and teacher while moving the students towards individualized mastery learning. In the researchers' opinion, "with technology, assessment can become richer, timelier, and more seamlessly interwoven with multiple aspects of curriculum and instruction" (p. 130), which also connects with Black & Wiliam's (1998b) concept of formative assessment and instruction being indivisible. A particularly interesting concern noted is that as we are just beginning to see how to harness technology to support assessment, there is much to learn about the quality and efficacy of these systems.

McKnight et al. (2016) also addressed a broad scope of technology in the classroom, without a specific focus on formative assessment or mathematics, but identified observations and conclusions once again worth noting. In justifying their own research, which included focus groups, interviews, classroom observations and online surveys of seven exemplary schools across the US, they noted a lack of documentation of how teachers used technology to improve learning. One of the five benefits of technology from their results was how technology can enhance communication and feedback. Teachers used technology to provide just-in-time feedback to students and the teachers felt the student-peer-teacher feedback loop, previously mentioned by Wiliam and Thompson (2007), blurred the traditional roles in the classroom so that all collaborators were learners. In what becomes a common theme in the studies found for this research review, McKnight et al. (2016) stressed the importance of professional development, technology support and infrastructure, as well as the importance of how the technology integration takes place. This research study focused once again on the general use of technology, but in a high school setting and was limited, self admittedly, by the sites they chose for the exemplary implementation of technology. In my opinion, this study may be quite helpful to others working with technology in the classroom giving both guidelines and suggestions for effective practices.

Narrowing the scope from broad technology-based formative assessment research to that specific to the mathematics classroom, Schroeder and Dorn (2016) conducted an action research study of a flipped university calculus course. Based on student questions and comments on the homework videos they were to watch, Schroeder and Dorn analyzed the student responses (and subsequent responses from their peers or instructors) and how the instructors used the responses to modify instruction. From the researchers' and instructors' point of view, the feedback was useful in that it drove lesson modification which resulted in instruction tailored to specific students' needs. According to the open-ended response survey given to students at the end of the term, most students felt the annotations (whether their own or their peers) assisted in understanding the course content and affirmed that they were not the only student struggling with the material. One response of note, six of the 19 students indicated they did not like that the annotations were required and part of the course grade.

In a study of university students in Sweden and the US, Bälter, Enström, and Klingenberg (2013) offered students in different subject areas web-based quizzes in a variety of courses for the first few weeks of each course based on the week's lecture material. The quizzes were intended to provide formative feedback to support students' learning. In the student survey and interviews conducted for the study, the majority of students felt it was important they were able try the quizzes multiple times (with a variety of questions) but that overall the quizzes did not encourage them to study more (20% reported they studied more). Students did not report feeling stressed about taking the quizzes, but interestingly some students felt the quizzes should be worth bonus marks, in some ways opposing the findings of Schroeder and Dorn (2016). The teachers perceived that students' results were improved compared to previous classes. One of the short-comings of this study, in my opinion, is that the quizzes were only given for the first few weeks of the course with the main intention to encourage students to study early on in the courses. Although it was the intention of the researchers (and in the title of research article), the fact that minimal feedback was given (only right or wrong) and that the results were not used to modify instruction would lead me to conclude that these were not entirely formative assessments and would not satisfy the definition of formative assessment that I am using in this study.

Roschelle et al. (2010) conducted a randomized experiment to examine the effectiveness of feedback from handheld technology (TechPALS) on elementary students' engagement and learning of fractions. Although not specifically designed for formative assessment, the teacher received feedback on each students' progress and the software encouraged students to discuss answers with each other, so in my opinion, the software provided opportunities for formative assessment. Students in the TechPALS condition were found to learn more than their peers, who were also using a technology-based product, but individually instead of in groups, with effect sizes ranging from d=0.14 to d=0.44. Although this was a fairly small study (n=173), three schools in the San Francisco Bay area participated and the researchers felt the students were distributed across a number of different ethnic groups. The researchers also found the limitations of the technology, with a high breakage rate (about 20% broke over the three-week period) and as much as seven minutes per day wasted on set up. Although the researchers conjectured that the technology would reduce the barriers to implementing feedback well, they found the delays and failures in technology lead to a reduction of time on task. Their conclusion was that the technology needs to be more reliable before one could reasonably claim it made it easier to implement cooperative learning well. At the same time, they reasoned that there was promise in the technology in socializing learning and encouraging positive behaviors such as asking questions and discussing disagreements.

Although not initially introduced for the mathematics classroom, Beatty and Gerace (2009) introduced their research based pedagogy for using classroom response systems specifically in the science classroom called technology-enhanced formative assessment (TEFA). In a later study, Lee et al. (2012) did include mathematics classrooms in their data by drawing on the similarities between science and mathematics classrooms, and as such, I believe TEFA can be applied to the mathematics classroom as well. According to Beatty and Gerace (2009), the proposed TEFA pedagogy is based both empirically and theoretically, drawing on on-site professional development programs with middle and high school teachers and incorporates multiple research traditions.

TEFA is based on four key principles:

1. Motivate and focus student learning with question-driven instruction
2. Develop students' understanding and scientific fluency with dialogical discourse.
3. Inform and adjust teaching and learning decisions with formative assessment.
4. Help students develop metacognitive skills and cooperate in the learning process with meta-level communication (Beatty & Gerace, 2009, p. 153)

Although developed from their own literature review and empirical data, Beatty and Gerace found good agreement between these four key principles and the four constructs stated by Roschelle, Abrahamson, and Penuel (2004) connecting computer response systems to the broader education research literature. I believe there also exists a connection between these four principles and the five key strategies outlined by Wiliam and Thompson (2007). The first two principles align with Wiliam and Thompson's first and second strategies, clarifying and sharing learning goals for success with learners and engineering effective classroom discussions and questions that elicit evidence of student learning. Although not a direct correlation, I believe motivating and focusing student learning can be attained by making sure that students are clear on the goals for learning so that they have success. The third principle aligns with the third strategy, providing feedback that moves learning forward. Once again not the same language, but formative assessment includes the feedback loop that moves learning forward, from both the teacher and students' perspective. And the last is possibly the strongest connection, since helping students develop metacognitive skills and cooperate aligns well with activating students as owners of their learning and as resources for each other. This alignment of strategies, principles and constructs across the literature leads me to believe these basic ideas may be integral to technology-based formative assessment in the mathematics classroom.

Beatty and Gerace (2009) found that classroom response systems (CRS), such as clickers, allow for students to be anonymous and yet still accountable. Anonymous in that their answer is not revealed to other students making it relatively low stakes for the student, but accountable in that they are required to key in an answer to the question. They noted that although this can be achieved via paper forms, it is too slow for real-time formative assessment. CRS also allow a teacher to collect answers from all students in the classroom rather than the few who put their hand up and can give a distribution of the answers so that upon a quick glance, the teacher is able to get a "temperature" of the classroom. Finally, by recording the student responses, a teacher is able to use the data for subsequent reflection, for both the class and individual student needs (Suurtamm et al., 2010).

With all of the previously mentioned benefits, there are of course also downsides to technology use in the classroom. In a broad sense, although we often perceive students to be experts and comfortable with technology, this is often not the case when students are expected to use technology in an academic setting (Messineo & DeOllos, 2005; Swallow, 2015). In fact, this lack of comfort and confidence "could translate into students' being less willing to take risks with technology" (Messineo & DeOllos, 2005, p. 53) and reduced confidence in their skills. This is extremely concerning when dealing with a mathematics classroom where many students are already lacking confidence in their mathematical abilities (Boaler, 2002). Combine these barriers with the extrinsic and intrinsic factors also affecting the teacher when implementing TEFA (see Figure 2) (Lee et al., 2012), and there are many factors affecting the implementation of technology-based formative assessment in the mathematics classroom.

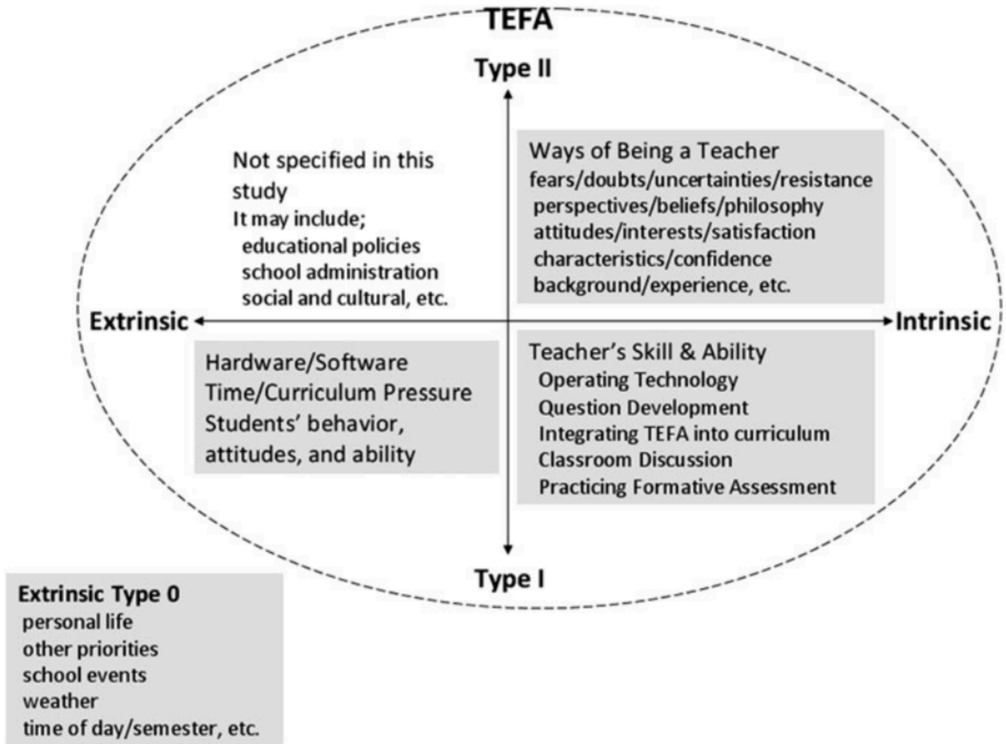


Figure 2. Extrinsic and intrinsic factors (Lee et al., 2012)

According to Lee et al. (2012), teachers must fight the extrinsic battles of finding time to prepare the activities, feeling the pressure to finish the curriculum, and dealing with students who may need time to understand how to properly use the technology. All the while, the teachers must intrinsically be confident in their own use of the technology and integrating it seamlessly into the classroom. A parallel may be drawn here to the Technological Pedagogical Content Knowledge (TPCK) model, where teachers must be adept at navigating the complex roles that content, pedagogy and technology play in implementing thoughtful pedagogical uses of technology (Mishra & Koehler, 2006). Just as teachers must be supported in finding the thoughtful pedagogical uses of formative assessment (NCTM, 2014; Suurtamm et al., 2010; Suurtamm & Koch, 2014; Wiliam, 2007), they must also be supported when implementing technology in the classroom (Hechter & Vermette, 2013; Lee et al., 2012; NCTM, 2014; Swallow, 2015). In my opinion, many of these barriers are one and the same as the barriers to implementing formative assessment in the classroom. Whether it is formative assessment or technology-based formative assessment, many of these barriers must be overcome by the teacher to implement effective formative assessment activities. Understanding the perspective of students with respect to the use of technology for formative assessment purposes in mathematics classrooms may provide information to help overcome these barriers.

From cost of technology to teacher and student confidence, the barriers from implementing technology and formative assessment are almost overwhelming. At the same time, "with technology, assessment can become richer, timelier, and more seamlessly interwoven with multiple aspects of curriculum and instruction" (Pellegrino & Quellmalz, 2010, p. 130). Ideally, the benefits to formative assessment and technology meld into one in the mathematics classroom, creating the moments of contingency, then immediately acting on them; giving students opportunity to become active learners and owners of their learning while giving the teacher immediate insight into the students' thinking.

Summary and Conclusion

Although the ability to gather information from students has been available for years, in my opinion, never has it been possible for information to be gathered and used to inform instruction so quickly or easily. This literature review attempts to first address the definition of formative assessment, while weaving in some research studies specifically addressing technology-based formative assessments in the mathematics classroom. Black and Wiliam's (2009) definition formative assessment was used as I felt it captured the importance of the multiple parts and participants in formative assessment. Feedback must be provided, but can only be considered formative when used to inform the next steps in learning for teachers and students.

Technology-based formative assessment is incredibly complex and requires a delicate balance of social, pedagogical and technological systems (Pachler et al., 2010). Just as with defining formative assessment, this delicate balance requires teachers and learners to engage with each other to see the intended positive effects. The research base for this area is continually growing and in responding to the calls for research in this area, I believe this study will contribute to the research base of technology-based formative assessment in the mathematics classroom.

Chapter 3: Methodology

In this chapter, the focus will be the methodology of this study. A brief description of phenomenology, which is a qualitative research approach I drew on in the study, as well as my bias as a researcher will be introduced. Finally, the sampling and recruitment method, data collection and analysis, and ethical considerations will be considered.

Phenomenology

Phenomenology is a qualitative research theoretical tradition in which the central goal is to describe "the meaning for several individuals of their lived experiences of a concept or phenomenon" (Creswell, 2007, p. 57). This phenomenon may be an emotion, a relationship, a program, an activity, or a culture (Patton, 2002). Phenomenology was first used by German philosopher Edmund Husserl and was introduced as a major social science perspective by Alfred Schutz (Patton, 2002). Phenomenologists focus on reducing the individual experiences of individuals into the universal essence of the phenomena (Creswell, 2007). This essence is a description of "what" the group experienced and "how" they experienced it (Moustakas, 1994). In other words, this essence focuses on what all participants have in common as they experience phenomena (Creswell, 2007).

Methodology

A phenomenological approach is well suited to needing to understand several individuals' common or shared experiences of phenomenon in order to develop practices and policies or to develop a deeper understanding about the features of phenomena (Creswell, 2007). As the purpose of this study is to examine the lived experience of students who participate in technology-based formative assessments, a phenomenological approach inspired the qualitative research methodology that was used in this study. By examining the students' experiences using a phenomenologically influenced research method, a better understanding of how technology-based formative assessment is experienced by the students was gained which helps to inform practices in the future. A critical component from phenomenology that was used in this qualitative research study is the engagement in epoche, a Greek word meaning to refrain from judgment (Moustakas, 1994). During epoche, the researcher "looks inside to become aware of personal bias, to eliminate personal involvement with the subject material, that is, eliminate, or at least gain clarity about, preconceptions" (Patton, 2002, p. 485). Although I have listed my personal biases about technology-based formative assessment below, it is also important to note that epoche is an "ongoing analytic process, rather than a single fixed event" (Patton, 2002, p. 485) and therefore was an important ongoing process during this study. This process involved the reading of my personal biases prior to beginning to read through the interview transcripts. I also made a conscious effort to set aside the findings from the literature review and preconceptions on how I believed the experiences may be connected. As I collected the data, there was a natural tendency to try and see the connections, but at the very least I was aware of this during the process. During each interview, reading and coding of the transcripts, I tried to focus on the individual student, not the group. This process allowed me to attempt to identify the lens I would view the interview transcripts with and reminded me to focus on the words of the students and allow them to speak their true experiences. Although this process is idealistic at best, it did remind me of my preconceptions before reading through the student responses.

Personal Bias – Epoche

Although impossible to completely remove personal bias from a qualitative research study, it is important to acknowledge and be aware of the personal biases that exist (Patton, 2002). I acknowledge the following biases towards the topic of technology-based formative assessment:

- I enjoy using technology in the classroom and embrace the challenges presented when evaluating a new piece of technology. I am a teacher who embraces technology in the classroom, using it whenever I feel it can further engage my students in material or allow them to do things not otherwise possible (physically or time-wise). I also believe we have a duty as teachers to model proper and effective use of technology. This includes addressing students who are not using the technology properly and engaging students to talk to each other during the process.
- I believe it is important to use technology that is accessible. This means the applications should be available on a variety of devices (not restricted to one) and that the applications should be cost-effective.
- I believe that my experiences with Desmos, Google Forms and other tools have been beneficial formative assessment tools, which may influence the way I reflect on student responses in the data gathering process. I believe I have had success using technology in the classroom in a variety of ways. I feel that I have better insight into my students understanding of mathematics
- Perhaps most importantly for this study, and I believe students enjoyed the activities we have done. From both their in-class reflections and course evaluations, students have been generally positive about these activities. These responses along with my own previously mentioned biases may influence the way I think about students' responses in the data gathering process.

Study Recruitment and Ethical Considerations

Prior to accessing potential participants, ethical approval from the Education Nursing Research Board at the University of Manitoba was obtained. Permission was also sought from the school to contact the students in an email including a brief description of the study to the principal (Appendix B). Once permission was received from the school, former students from my Pre-Calculus 30S and 40S classes were invited to participate by distributing a message through the school's online community (Appendix C), a learning management system that is used by the school for internal communication. A clear outline of the study, as well as an encouragement to participate whether students have had positive or negative experiences, was included in the message.

Of the twelve former students who replied to the initial recruitment letter, only one was able to schedule an interview in the time frame intended for the interviews to take place, with the others having conflicts with travel and work. This student forwarded the recruitment letter to the students he had updated contact information for, and five additional participants were recruited, to bring the total to six. When the former students contacted the researcher expressing their interest, a further explanation of the study as well as two copies of a consent letter (Appendix D) was provided. One copy of the consent form was kept by the students and the original was retained by the researcher. All participants were made aware that their participation was voluntary and that they may withdraw from the study at any time. Once these particulars were in order, an interview time was scheduled, with all interviews taking place after regular school hours in the school library.

At no point were any of the participants' names or any closely identifying information included in any documents generated from this study. All information received from the participants was kept in an area to which only researchers involved in this study have access. Consent forms were stored in a separate place from the data collected. All data was kept in a locked area and the data will be destroyed after seven years from the publication of this study. Research participants were not compensated for their time.

Study Participants

Six students who were members of my Pre-Calculus 30S and 40S courses were recruited to participate in this study. These students had experienced the technology-based formative assessment in either Pre-Calculus 30S and 40S, or both, with me as their teacher. As these students have graduated from high school, I am no longer in a position of power over the students. My initial intent was to use purposive sampling to select participants from those students who expressed interest in the study, so as to obtain the broadest range of information possible (Yin, 2011). However, as only six students were available, they were the six I interviewed. A more detailed description of the study participants is found in Chapter 4 and although only the six students were available, they did have a range of experiences and varying degrees of success with the course.

Data Collection

As the aim of this study was to gather the experiences of students using technology-based formative assessments, the primary data source was structured interviews with open ended questions developed by the researcher (Appendix A). Each participant was asked the same question, with the indented question intended as a follow up question if needed. This interview style allowed respondents to answer the same questions which facilitated organization and analysis of the data while permitting evaluators to see and review the instrument used (Patton, 2002). There was a single round of interviews, completed just under a year after the course had taken place. The interviews ran for 20 to 45 minutes in the school library after classes had completed for the day to give some consideration of privacy to the participants.

Artefacts from the courses were used to prompt more vibrant descriptions of the experiences of the students (Appendix A). These artefacts were shown to the students on a computer and consisted of examples of both Google Forms and Desmos activities used in class.

The interviews were recorded using recording software on a laptop with an iPhone as a backup. During the interviews, I kept a research journal, recording notes and observations during the interview and my reflections on each interview once it had finished.

After the interviews took place, I transcribed the interviews and saved the files to a password protected hard drive, which were backed up on a password protected external drive. Once the interviews were completed and transcribed, the transcripts were sent to the participants for member checking. Four of the participants replied that they felt the transcripts properly captured their responses, while the other two participants did not respond. In addition, the option of a follow-up interview was given to the participants clarify or elaborate any issues from the initial interview but the participants declined, stating the transcripts accurately captured their experience.

Data Analysis

After the initial transcription, each interview was listened to in full while reading through the transcript to ensure its accuracy. Then, the transcript was read through twice to fully immerse in the experience of the student. Once again during this process, I made a conscious effort to focus on the individual student and what their experience was instead of immediately looking for connections. I utilized concept coding (Saldaña, 2016) to begin a first round of coding of the experiences for each individual transcript after reading through each transcript two times. A concept is “a word or short phrase that symbolically represents a suggested meaning broader than a single item or action” (Saldaña, 2016, p. 119). Concept coding helps to identify themes that help form “a ‘bigger picture’ beyond the tangible and apparent” (Saldaña, 2016, p. 119). After this initial coding process, a second review of the transcripts allowed for further codes to surface. Once this second round of coding was completed, the transcripts were compared to begin to form the three themes that my analysis noted. Special care was also taken to record responses that did not fit into the three general themes that I still felt were of note.

This chapter discussed the details of the qualitative research methodology that was used in this research study. This study was influenced by a phenomenological approach and as such, my personal biases were described. Finally, the details of the study recruitment and ethical considerations, as well as the data collection and analysis were described.

Chapter 4: Results

This chapter describes the results of this qualitative research study examining the experiences of students with technology-based formative assessment. As the first two research questions are concerned with the students' reflections on how the technology-based formative assessments have affected their learning and the commonalities in these experiences, this chapter will also address these research questions. First, to set context for how and why these tools were used, a description of the workflow used in the Pre-Calculus classroom will be outlined. Following this description, an introduction to each of the six participants will be made, a summary of their own responses and the common themes across each of their interviews will be discussed.

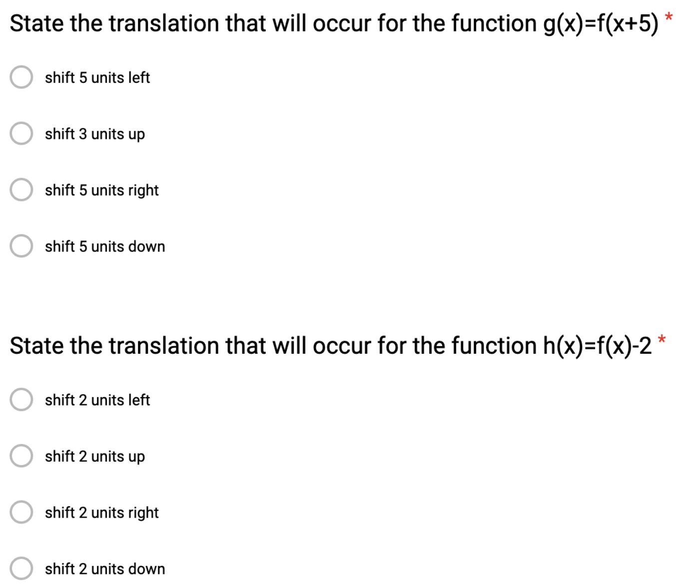
Class Use of Google Forms and Desmos

To provide a context for the comments of the participants and enable a deeper understanding of the analysis of the interview data, this section will describe how Google Forms and Desmos were used in the class setting. As previously mentioned, I used these tools in essentially the same way in both Pre-Calculus 30S and 40S and as such, "in class" will refer to both of these courses moving forward.

Google Forms.

Google Forms is a website that can be used to create surveys, questionnaires and quizzes. Questions can be created in a variety of different types but in class, multiple choice questions were the only type I used. When multiple choice or short answers questions are used, the creator of the form can indicate the correct solution. When the form is filled out and submitted by a student, it is automatically marked and the result is emailed to the student. I used Google Forms as an entrance slip type activity, what I called a Next Day in class. These activities were created using questions from the previous class and deployed in two ways. The first approach I used was the Google Form discussed in this study. The second approach I used was a pencil and paper long answer question completed by the students which was checked a variety of different ways. Some days, the students would check their own answers against the answer key projected onto the board. Other days, they would be randomly partnered with another student and then exchange sheets and check each other's work against the projected answer key. They were then asked to have a discussion about their answers and compare the differences in their solutions even if they both got the final answer correct. While the students completed both types of Next Days, I would circulate the classroom to answer questions and take a look at how the students were doing in general. The electronic and pencil and paper Next Days were alternated and took place almost every class. In this study, the students were asked to focus on their experiences with the Google Form Next Days, and were shown samples of these Next Days from class to help them to recall their experiences with them. The experiences discussed in this chapter are of the Google Form Next Days, unless specifically noted to be of the paper and pencil Next Day experiences.

When the bell rang, students were supplied the URL for the Next Day activity on the school's learning management system, which they filled out and submitted using either their own device or using a device provided by me. The reason for beginning the class with the Next Day activity was to give the students an opportunity to review the material from the previous class as well as check their understanding of the material. This helped to ensure the entire class was on the same page with where we had been before we continued to the next topic or extended the previous topic. Most days the activity was completed independently, but the students were also encouraged to work with a partner. When completing the Next Day, students were not discouraged from asking for help on the days where they were to try it on their own. Next Days on Google Forms generally consisted of 10 to 15 questions and students were given approximately 10 minutes to complete the activity. As previously stated, questions were in multiple choice form, with a sample of the types of questions shown in Figure 3.



State the translation that will occur for the function g(x)=f(x+5) *

- shift 5 units left
- shift 3 units up
- shift 5 units right
- shift 5 units down

State the translation that will occur for the function h(x)=f(x)-2 *

- shift 2 units left
- shift 2 units up
- shift 2 units right
- shift 2 units down

Figure 3. Google forms sample questions

As previously stated, after the student submitted the Next Day they received an email with their mark and each question with the correct response shown. After the time allowed for the activity, I would project the results page of the Google Form which showed the average, median and range as well as the frequently missed questions (shown in Figure 4).

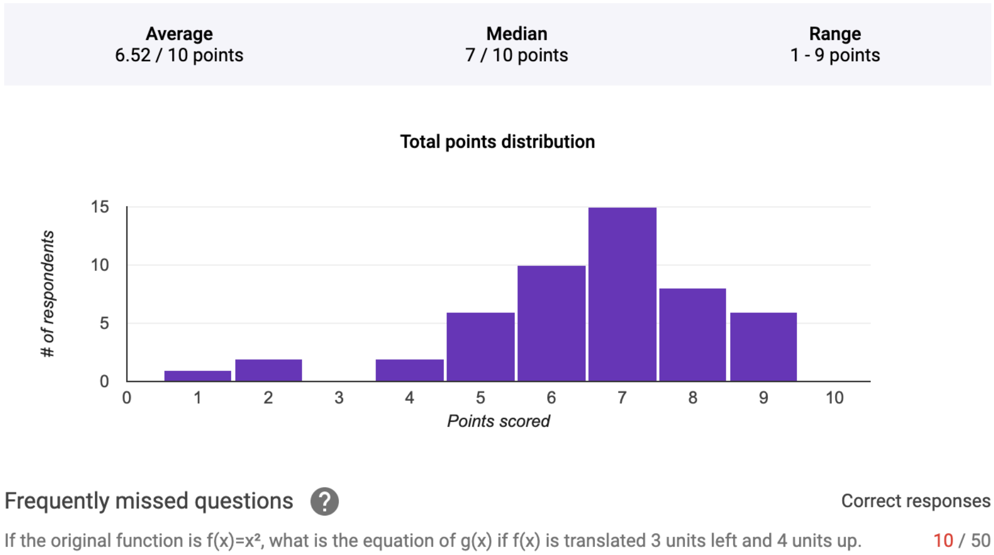


Figure 4. Results page

After discussing the overall class average, I would go through each question with the class, spending the most time on the frequently missed questions. A question by question summary was also used (see Figure 5), with an effort made to discuss the distractors in each of the multiple-choice questions to try to address misconceptions.

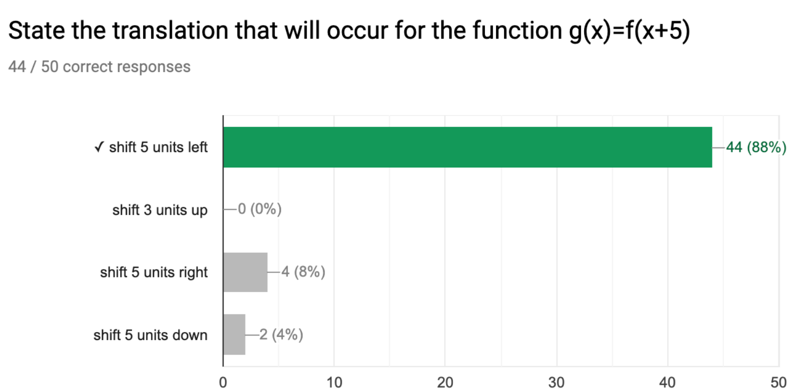


Figure 5. Single question result summary

As the teacher in the classroom, I used Google Form Next Days to get a quick snapshot of the class' understanding, usually of the lower level ideas from the previous class. I appreciated how it quickly showed me the class' results and allowed me to see if there was anything that needed to be addressed before moving forward. The ability to show results of the class while not singling any one student out was powerful to me as it was my intention to give students an understanding of where the entire class was in their understanding of the material and make the decision whether to continue with new material or to continue to work with the material from the previous day. It also allowed me to identify students who were struggling with the material. Although this intervention was not as drastic as it maybe could have been in designing specific material for the student, it did allow for a conversation to happen during class about what the student felt was needed to to gain a better understanding of the material. Some days, it was that the student was just not engaged because of other circumstances, but some students did take the opportunity to set up a meeting outside of class time to review the material. These Google Forms also fit well in the online portion of the course. Since all of the activity booklets the class worked through were posted on the class Google Drive folder along with the answer keys, along with a paper Next Day activity and a short video on each topic, these Google Forms were able to be placed on Google Drive and were accessible to students after class (see Figure 6).

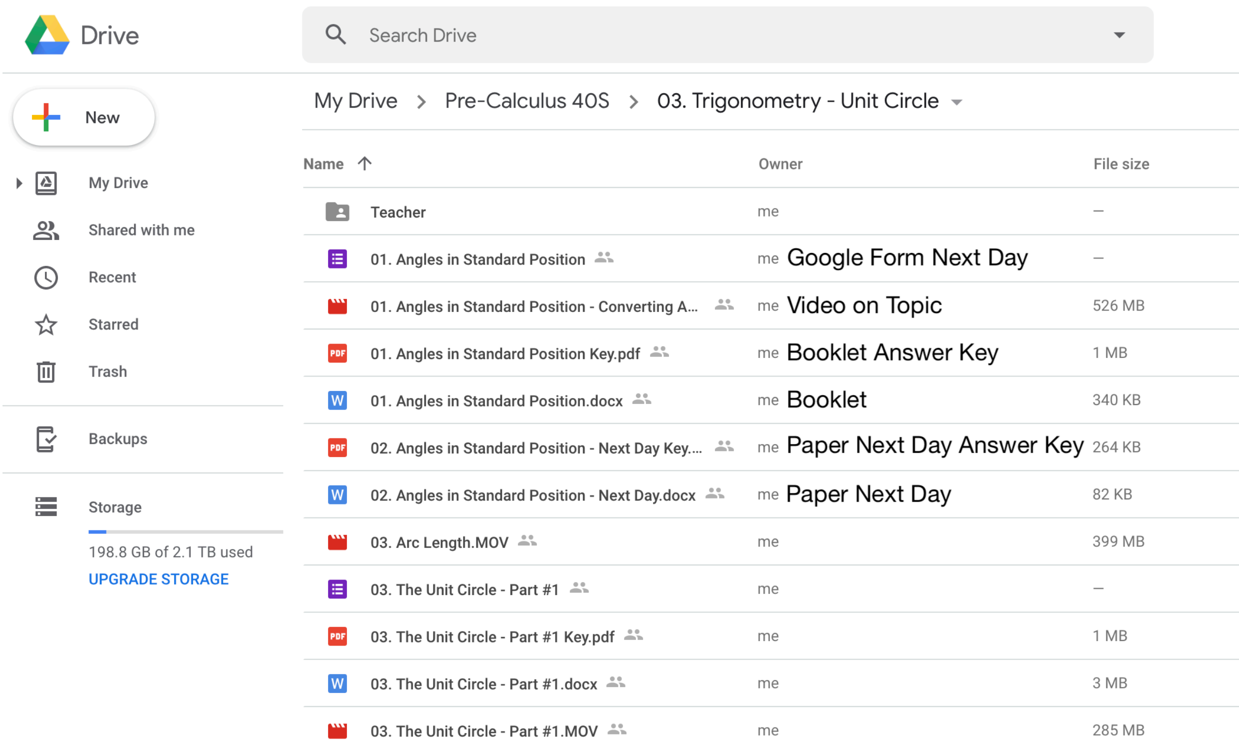


Figure 6. Class Google Drive folder organization

Desmos.

Although Desmos began as an online graphing calculator, it has since transformed into a website full of activities where students can explore mathematics in a visual and hands on way. Desmos was used in a variety of different ways in the mathematics classroom, such as the previewing of new material or the learning of new concepts but the use of Desmos described in this research paper is as an activity after the new material had already been taught, either in a direct instruction or in a pen and paper booklet activity. These activities were used in the middle or at the end of a lesson to gauge student understanding.

Since Desmos activities cannot be completed on a mobile phone, the workflow for the Desmos activities differed from the Google Form Next Days. To ensure all could properly participate, students picked up an iPad from an iPad cart at the beginning of class on the days when Desmos activities were being completed. Once again, students were given the URL to the activity on the school's learning management system and then given anywhere from 20 to 30 minutes to complete the activity.

Two different types of activities were done with the end goal of being formative assessments. The first was the Desmos designed Polygraph activity (desmos, 2019) (see Figure 7). In this activity, students are randomly paired up and then given a grid of functions, where the specific tiles change depending on the unit. One student (the "picker") chooses a function which is known only to them, and then the other student (the "guesser") asks questions that can be answered with a yes or no answer until they feel they have enough information to make an educated guess of the correct function. The "guesser" continues to ask questions and narrow down the possible solutions until they have one graph left to choose. They are then notified whether the graph is correct or not by the Desmos system. This activity usually occurred in the middle of a lesson after the function had been discussed but before completing any complex graphing problems.

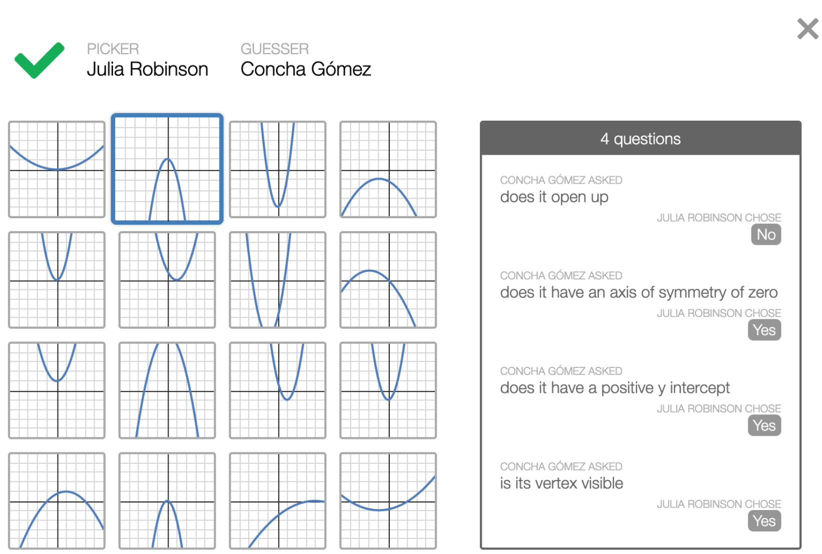


Figure 7. Polygraph activity

In my opinion, the goal of this activity was to see how students utilized the vocabulary discussed in class and to give them an opportunity to practice using the vocabulary in an appropriate manner. As the teacher, I had access to the dashboard (see Figure 8) which showed all the activities currently being played live, as well as a running tally of each student's success in identifying the correct function. I was able to identify and stop by students who were struggling with the game and identify what they were struggling with or if they were just not engaged by the game. The ability to pause and anonymize the students (see the bottom left of Figure 8) made this a unique opportunity to get the attention of the entire class and highlight the successful use of vocabulary in certain instances. It also allowed me to issue challenges to the class, such as to see what the minimum number of questions that could be asked to narrow down the options to a correct graph. This often engaged students who were tiring of the game for a few more rounds.

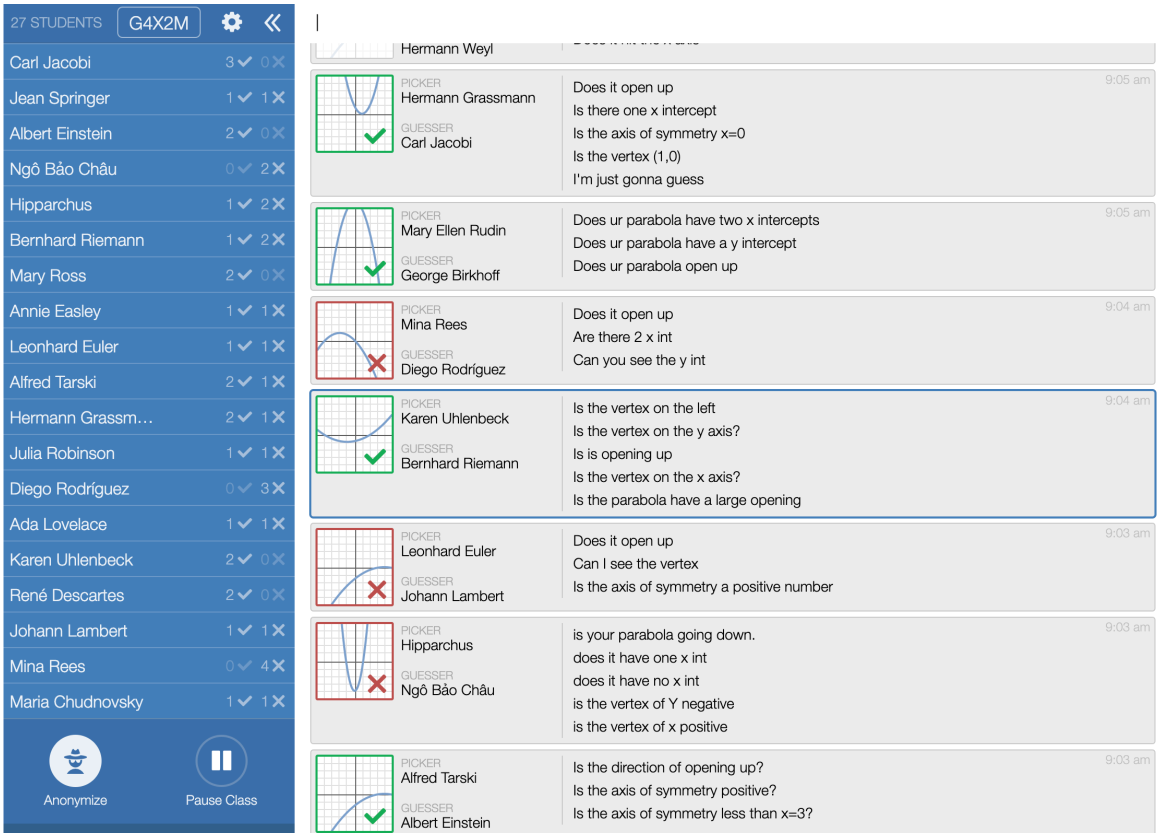


Figure 8. Teacher dashboard in Desmos Polygraph activity

The second type of Desmos activity was a teacher designed activity where students used graphs to answer questions about the equation of a function (see Figure 9) and then test their understanding of that function using a matching activity where they combined words, equations and graphs representing the same function (see Figure 10).

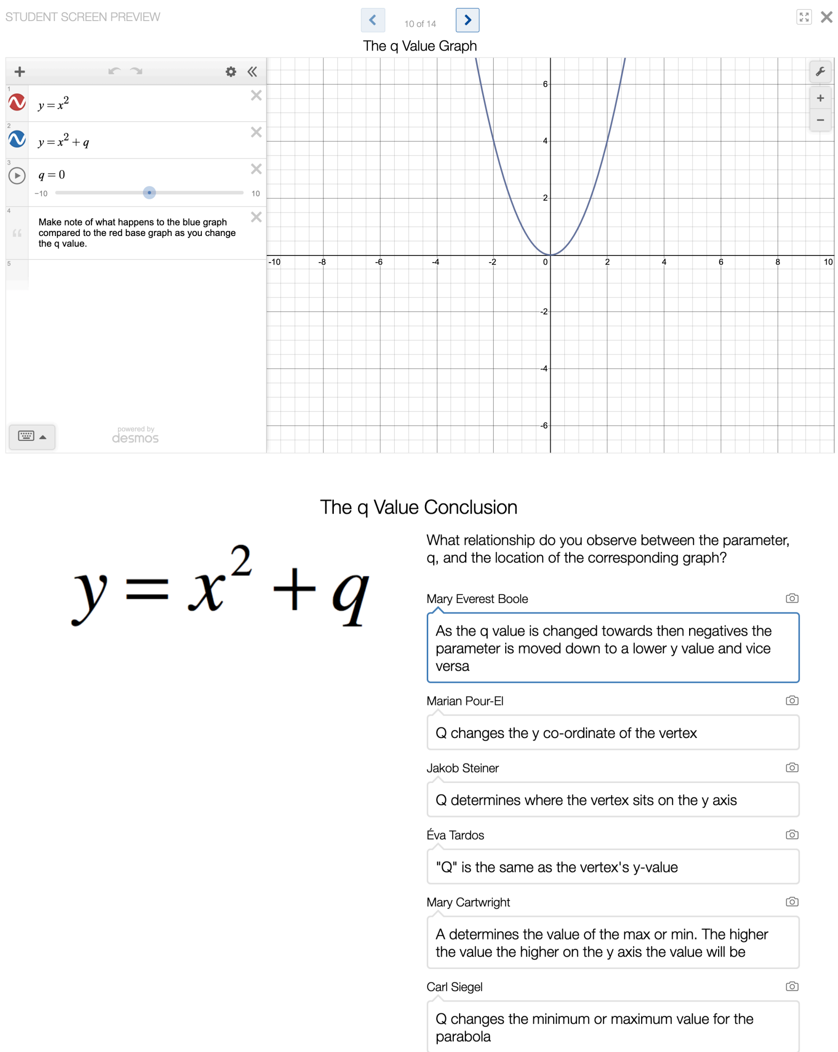


Figure 9. Student slides from teacher designed Desmos activity

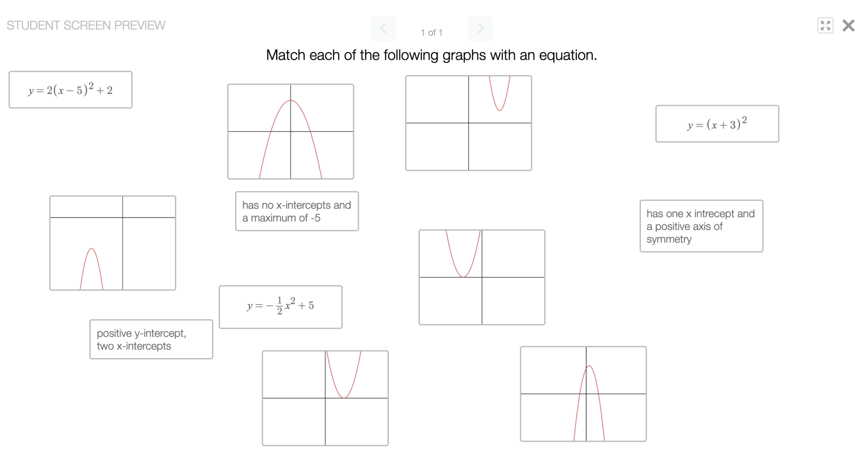
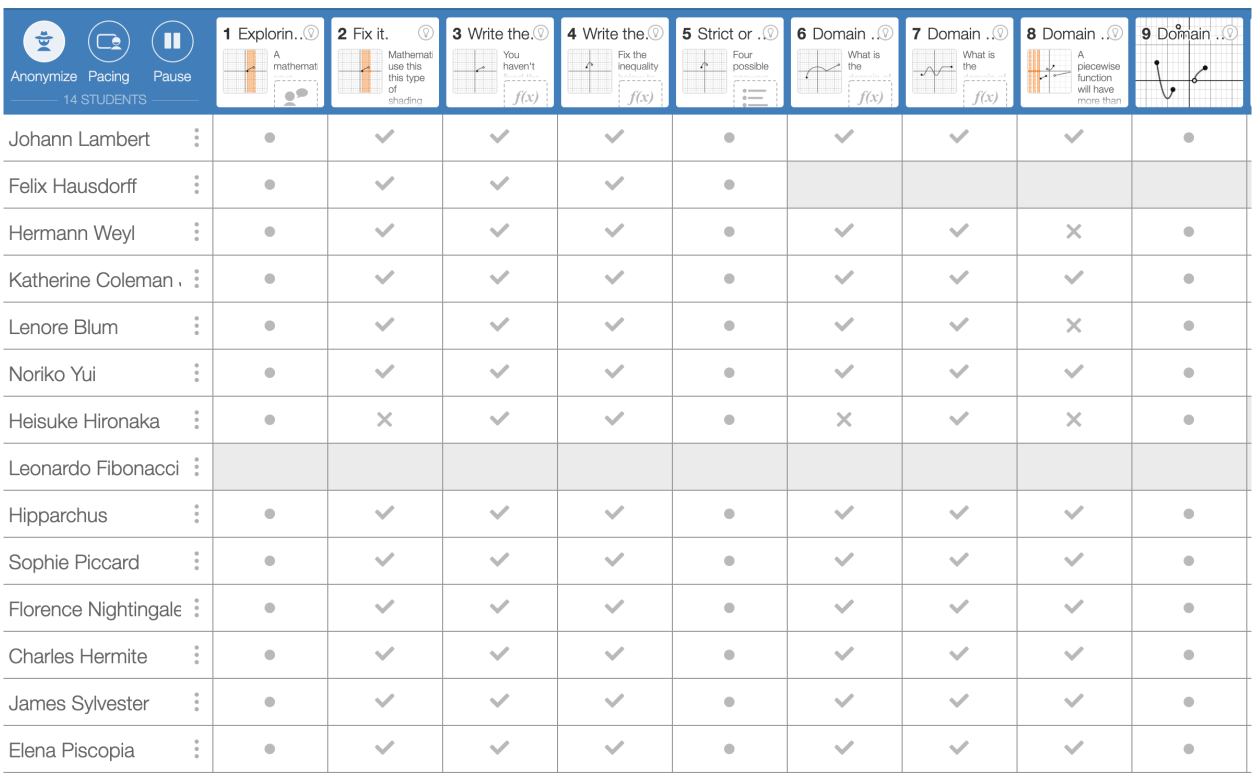


Figure 10. Matching slide from Desmos activity

Students worked through these activities on their own and in groups of two, depending on the day. Students received feedback in a variety of different ways depending on the activity. For some of the activities, I would project the teacher dashboard (with anonymized names) on the board showing the student responses (see Figure 11). The students could then see which answers they got correct or where they needed to go back and look at the solutions. Other days, I would use the pacing function, which only allowed the students to progress to a certain slide before stopping and having a discussion as an entire class about the solutions and the reasoning behind the solutions.



Anonymize Pacing Pause 14 STUDENTS	1 Explorin..	2 Fix it.	3 Write the.	4 Write the.	5 Strict or .	6 Domain ..	7 Domain ..	8 Domain ..	9 Domain ..
Johann Lambert	•	✓	✓	✓	•	✓	✓	✓	•
Felix Hausdorff	•	✓	✓	✓	•				
Hermann Weyl	•	✓	✓	✓	•	✓	✓	×	•
Katherine Coleman .	•	✓	✓	✓	•	✓	✓	✓	•
Lenore Blum	•	✓	✓	✓	•	✓	✓	×	•
Noriko Yui	•	✓	✓	✓	•	✓	✓	✓	•
Heisuke Hironaka	•	×	✓	✓	•	×	✓	×	•
Leonardo Fibonacci									
Hipparchus	•	✓	✓	✓	•	✓	✓	✓	•
Sophie Piccard	•	✓	✓	✓	•	✓	✓	✓	•
Florence Nightingale	•	✓	✓	✓	•	✓	✓	✓	•
Charles Hermite	•	✓	✓	✓	•	✓	✓	✓	•
James Sylvester	•	✓	✓	✓	•	✓	✓	✓	•
Elena Piscopia	•	✓	✓	✓	•	✓	✓	✓	•

Figure 11. Teacher dashboard for teacher designed Desmos activity

Kahoot (http://kahoot.com) was also used in the classroom as a technology-based formative assessment but was not included as one of the activities discussed in this paper. This was due to the fact that it was not used as consistently in the Pre-Calculus 40S courses as it was in the Pre-Calculus 30S courses. In the Pre-Calculus 30S course, it was used as a review prior to the monthly tests as well as for the midterm and final exam. This explanation has been included as one student referenced the activity in their interview.

Once again, my goal in these activities was to instantly assess student understanding of the new material we had just completed in class through other learning activities, such as paper and pencil or mini whiteboard activities in small groups or direct instruction. These activities were often used as exit tickets to summarize and conclude the day's lesson. There were also times where the new material was presented in the Desmos slide deck and the formative assessment was built in to the learning of the new material. The ability to anonymously share and highlight student responses was powerful for me, especially when I could use responses from students who would not normally have spoken up in class to share an interesting solution. Not only was I able to get a sense of where the class was in general and make changes to the lesson accordingly, I was also able to have one on one discussions with students when necessary. I also felt that the students could see definitions and math phrases written by their peers and in a different way than I would have written them, opening the possibility for a deeper understanding and an opportunity for discussions in the classroom.

Description of Participants

Six participants were recruited from my former students in Pre-Calculus 30S and 40S mathematics courses. All graduated from the same class from a grade 9 to 12 high school in Winnipeg. Four of the participants were enrolled in my classes for both Pre-Calculus 30S and 40S and the other two were in either Pre-Calculus 30S or Pre-Calculus 40S. All six of the students have since graduated from high school. Google Forms and Desmos were used in a similar way in both courses, and this allowed for some comparison of their experience using these tools to other classrooms where other methods were used. For the purpose of reporting this qualitative data, the female pronoun has been used for each of the participants and the pseudonyms of Joyce, El, Nancy, Max, Erica and Robin have been assigned to the participants.

In this section, a short introduction will be made to each of the participants to help frame their answers further in the analysis section. The information in these introductions came directly from the interviews, not from my experience with the students in the classroom, and was member checked with each participant for verification. In each case, I attempt to describe the type of learner and their own assessment of their math interest and abilities, as well as the most commonly addressed strengths and weaknesses of the technology-based formative assessment activities from each participant.

Joyce was a student in both the Pre-Calculus 30S and 40S courses. She had to work hard at math and felt it was not something that came easily to her in a traditional math classroom. Part of this was due to her feelings of distractedness while dealing with ADHD but she also found "the more things where you kind of forced interaction, things that like you have to apply yourself, it's much easier." Joyce felt that overall, these activities were positive but felt that the paper and pencil Next Days activities were more useful in preparing for summative assessments than the Google Form Next Days.

El was a student in only the 40S class. As someone who enjoys math but "wouldn't usually, like, reread [her] notes the next day or reread whatever or go over anything", she felt that these activities were good at reinforcing the topics previously learned and gave an opportunity to "just kind of gauge, like, where you're at".

Nancy was a student in both Pre-Calculus 30S and 40S. She described herself as a very visual learner and more of a social sciences person and indicated she really liked these types of activities because "in a class like math, which is not like [her] thing, you know, [she had] a tendency to, you know, space out with things going in one ear and out the other so [she] could come back to class the next day and totally forget what [was being] talking about". She stated that as a "visual learner", she enjoyed Desmos activities more than the Google Forms.

Max was a student in only Pre-Calculus 40S. She still uses Desmos in her university courses today and enjoyed the Next Days for getting to practice and "get shown what were the most important things in the class" as well as some of the common mistakes. Max found that having to do the Next Days in every class was a negative but did also find it forced her to review immediately instead of waiting until just before the test. She also indicated that she is a "visual learner" and felt that Desmos led to a better understanding of how the parameters connected to what happened to the graph of a function.

Erica was a student in both Pre-Calculus 30S and 40S. She found that the use of technology as well as the repetitive and interactive nature of the formative assessments were what she enjoyed the most. She most enjoyed the Google Forms Next Day activities as it gave her a "constant, like, reminder of hey, [she needs] to, like, work on this sort of question or that sort of question".

Robin was a student in Pre-Calculus 30S only. She felt that even though she was not "the fastest learner", these activities helped her to learn and make math not "seem so horrendous as [it] sometimes can seem". She was always excited when the iPads came out and enjoyed the "different avenues you can take to learn the same thing". She also wrestled with the advantages and concerns associated with being able to compare herself with others. She felt negative some days when she felt she put the work in and still did not see the results she hoped for while on other days, she appreciated the safe place to struggle and allowed it to push herself to put more work in.

Common Themes

This following section will outline the three major themes that appeared during the coding process across each of the six interviews, which addresses the second research question of what commonalities exist in the students' experiences. These themes include both positive and negative experiences of the participants. Within each theme I attempt to describe the experience of each student. Following the major themes, some minor threads and unique responses (those not noted across all six interviews) and a reflection on what I determined to be significant comments from the participants are included.

Theme 1: "Back to math mode" – A personal check-in, a refresh or reinforcement and deepening of understanding.

The first theme that I identified from these interviews revolved around the students' internal check in and refresh of the material. This internal check in was a check against where they felt they were with the material and where they actually were in understanding the material.

Joyce felt that the technology-based formative assessments were an opportunity to "see if you're picking up the information or not and see, like, where are you messing up" and liked the opportunity to "kind of [have] feedback in between and before tests and quizzes". She felt that the ability to know "where you're at because most of the time you won't have that option to figure out what you're doing without it being marked and affecting your grades" had "a major impact, just getting feedback and knowing … where you're at". She did state that the Google Forms lacked, in the personal check sense, the ability to see exactly where she had made a mistake as they were just multiple-choice questions. She liked the paper and pencil version where she could have something more detailed to go back and reference.

For El, a word that was repeated many times in her interview was "reinforced". The ability to "instantly, like, right after learning it, just kind of re-remembering it the next day" was the highlight of her using the Google Form. She felt that this reinforced the material for her and helped her to understand and remember the material in the long term. This reinforcement continued with Desmos, and allowed her to "gauge, like, where you're at". She felt the best thing about these activities was that they weren't hard questions, and as such, she was able to have a good understanding to apply to the more difficult questions. Perhaps most importantly was her feeling of how this constant reinforcement helped in the long term with her understanding of the material. When asked of the most beneficial things about Desmos and Google Forms, she responded:

> It was just, it was just making sure that you could wrap your head around the idea of it, so that like when you are going back to it, then it's easy to remember and it's easy to, to apply to those hard questions. … So knowing, like, going back and looking at a couple of questions and being like, okay, like I can, I can kind of understand that. Then you kind of, you know, already have a place to start and then build from that.

Although I will come back to this quote in my comparison with Wiliam and Thompson's (2007) key strategies in Chapter 5, this quote stood out as moving forward from the check in/refresh that most of the participants talked about and more towards building a deep mathematical understanding of this material. As previously mentioned, El enjoyed math and part of this may have been because of her ability to use these activities to deepen her understanding. She was able to take the more fundamental concepts covered in the Next Day or Desmos activities and then apply them with a short review to the more difficult concepts covered during the class. My analysis suggests that she enjoyed the challenge of making connections between the different concepts and then applying it to the new or more advanced material. When a student is able to make those connections, Pre-Calculus 40s does become a series of "lightbulb" moments where new connections come every class, which I think is enjoyable as a learner.

Nancy, as a student in mostly social sciences, first mentioned the Google Forms Next Day activities allowed her to shift "back to math mode" and that this check in allowed her to "kind of jog [her] memory of, of what we had done". She went further saying how she enjoyed having a non-graded progress check that showed her what she needed to look at without "punishment for not getting it totally correct". She echoed El's idea of reinforcement, because it allowed topics to be carried over and "not just, you know, do one thing and then be done with it for good". These activities not only gave her "a refresher" of the material, but they also pointed out problem areas. She, like Joyce, also mentioned that the Google Forms were lacking in the ability to show her worked out solutions.

Max had a different outlook on how these activities allowed her to refresh the material. She described the importance of not only the activities being "a good recap of the class" but also how she got "to practice and then … get shown what were the important things in the class". She viewed having to do these activities after every class as negative, but also mentioned how these activities forced her to review the material every class, because usually she would just wait until the test. She also identified the fact that these check-ins allowed her to see some of the common mistakes made by the class with the topics and how this benefited her in the long run.

Erica also had a different sense of how the technology-based formative assessments allowed her to check in. She considered these activities to be a "good opportunity to, uh, check up on how, how, like, you processed the information you got, like from the day before." It indicated to her that if she did poorly, "then [she] knew that [she] had to, like, work on something. … that was a good, like, a constant, like, reminder of, hey, [she needed] to, like, work on this sort of questions or that sort of question." She also referenced how these activities allowed her to build on previous knowledge that occurs within the curriculum. Instead of just finding what she needed to work on, it also refreshed where we had been and allowed her to use this material to build on what was previously learned in the lesson that day. When asked about whether these were positive or negative experiences, she responded:

> Um, yeah, the positives for it was that it refreshed your mind. Cause a lot of times in school when you learn something and you go to bed, the next day you wake up, you don't remember it at all, and you go to class, then the teacher starts talking and then all of a sudden you're just like, what the hell is he saying? … So that's, that's what I liked about it since it was usually at the beginning of the class, it was like, okay, this is what we're talking about now and we might put another step onto this.

Erica also felt that these activities gave her the opportunity to not only go back and see what topics she needed to still work on immediately, but also in the long term, by going back and trying the activities before quizzes and tests. She also had a similar experience as Joyce, with looking at the activities as an opportunity to take "a quiz without being, like, worth marks, but at the same time you kind of know where you're at in the course or like, in the subject or the unit." She also went beyond the personal check in, acting when she did not do as well as she would have liked on one of the activities by asking me, as the classroom teacher, for help or access the resources on the class Google Drive folder.

For Robin, the Google Form Next Day activities allowed her to, even though she was busy with school and her personal life, “kind of get refreshed, you know, so you’re kind of at a par level a little bit when you, when the class starts…” The activities in general allowed her to see what she remembered and, in her opinion:

> the best way to do that is through, like, a little quiz or a little test ‘cause then you have to grasp within your own brain. If you can look at notes, that’s one thing. But if you can try and figure out with what you may remember may have practiced before, I think that it makes it go…

Like Erica, these activities also allowed Robin to check-in before building on the material with the next day’s new material. She described these activities affecting her learning:

> um, well I think to begin like, like I said, I think it allowed it to allowed myself to be more like organized like in my head, even like, just like, so when we would come into class and you could get a Next Day or you could get an Desmos or something. Like, if you're just in the regular math class where you just kind of open textbook, do questions, it's hard to like see like, especially with Google, sorry I'm bouncing all over the place. But especially with like those Google forums where you did the Next Day, you saw what you did yesterday and then you would write that same equation and write something similar. But how I would, you know, like how it like leapfrogs the next thing. So having an understanding of how the math works, like upwards that way. Like that. I think that was a big help for that. Cause a lot of time you go and the teacher would simply bring out a new, you know, 4.2 today, right? And you don't necessarily remember 4.1, or I didn't understand 4.1, but you're on 4.2 now. So it doesn't matter. But having, being able to at

> least generalize some kind of understanding of 4.1 and then move on to 4.2, you know what I mean? Like I think that in, in that sense it was, it was helpful.

Robin's response showed the importance of her being able to refresh the material from the previous day before moving forward with new learning. Although this was a powerful connection, she did feel frustrated sometimes when she would not do well on the activities. Although she admitted there were some days where she felt she did not prepare to the best of her ability for class, there were also times she did put the work in and sometimes this check in "hits you fast, you know, you're just off of lunch, out of gym, and we come in, it's like, um, like a mini quiz, not that it was any stress or anything, but you know, it was still there." She felt that as someone who self-identified as a student who took longer to grasp material, these activities could be frustrating on days where math was not clicking for her.

In general, all six students stated that the technology-based formative assessments were an opportunity to test their understanding of the previous day's material in what they perceived to be a non-threatening way, as opposed to a graded pop quiz or test. Although the words they used were somewhat different, from reinforce to refresh to forced review, I felt that these all were words for taking a personal assessment of where they stood with the material. These personal check-in experiences were mostly positive, but were not without some negative experiences from not understanding where the students' mistake was to being understandably frustrated on days where, although these were formative assessments, the students did not do as well as they would have liked. Their comments also reinforced the importance of using approaches that enable detailed feedback rather than simply correct or incorrect answers.

Theme 2: "A kick in the butt" or "some confidence" – A comparison opportunity.

A second theme that emerged from my analysis of the interviews was the opportunity provided to students to compare both their understanding and the result of the technology-based formative assessment activities with their peers. Similar to the first theme, this emerged from both positive and negative experiences and in some cases both a positive and negative experience for a single student.

Joyce appreciated the opportunity to see what other students were doing while being able to check her own understanding. Being able to see what other students were doing up on the screen was an important experience for her. But her experiences while working on these activities in groups was "a double edge sword". According to Joyce, "[i]t did make it easier sometimes, but I think a lot of times, especially when you're a very close grade and working with a lot of buddies, it's easy to get very, very off task." So although she did enjoy the ability to share ideas and work with her peers, it did provide an opportunity to be distracted. Joyce did find knowing

> how the class in general is … a very useful tool because [she thinks] it is easy to blame things that aren't true because you know, you want to feel better about yourself. I think you realize that you're way off the class average, I think, maybe, maybe it's just you are, or, you're not taking the extra time to figure out or you're not doing the work or something…

These activities allowed her to honestly assess her effort level when she did not do as well as the rest of the class. As she mentioned, this honesty came from being able to compare herself to the rest of the students. If she was the only student who did not have success on the assessment, she felt it was obviously something she was doing, or not doing, and that she could not pass the blame on to someone else. At the same time when she could see the class in general was struggling on a question that she was struggling with it gave her the understanding that "it's a harder concept to grasp and that [she's] not the only one who's, like, struggling with it." This sharing of the class results and answers made her feel that she was not the only student who did not understand the material. She also stated that "dealing with people that are working with the same thing at the same time … helped with retention a lot."

El had a similar experience to Joyce when describing how she compared herself to others when reviewing the results of the Google Form Next Day or Desmos activity. She mentioned

> some teachers don't say it's good, but I, I think it's always good to like kind of compare to others. 'Cause then it's, like, if everybody's doing bad then it's the teacher's fault, you know? Uh, so , but if, like, you're the only one doing bad, then it's like, okay, I have to, I have to figure some stuff out.

She was able to assess her relative understanding to the class and did not feel isolated when she was not successful. El specifically enjoyed the Desmos "word for word" student responses where she was able see "other people's take on it, 'cause some people think of things differently." In her opinion, this was helpful because it's sometimes difficult to understand my explanation and this provided another view on the idea. The fact that these results were able to be compared anonymously made her feel like I was not picking on anyone specifically. This anonymity did not fully extinguish all anxiety from the activities, as El stated that part of her was sometimes worried that she might be the one person who was wrong. Although this did motivate her to stay engaged in the lesson and not just "press this one and move on to the next one. You're not just guessing." She also enjoyed the competitiveness to the activities and this competitiveness encouraged her to strive for the correct answers.

Nancy found it helpful when the responses were put up on the screen and the class could see the results together in the Google Forms, but really enjoyed the visual component to the Desmos activity results. Being able to engage in a discussion and "see, like, these two people did this, and like, this is why it's wrong 'cause if you change this value, this is what it looks like on the graph" was "huge" for her understanding. When seeing results on the board she, like Joyce and El, appreciated being able to see problem areas for the entire class and used these experiences to figure out exactly what she needed to focus on. Perhaps her most positive experience was being able to work in groups on the activities. She said:

> Um, so like being able to talk it out and, you know, even just kind of learning from each other and figuring out like why you thought this and why I thought that, it can kind of help to compare notes, I guess, on like where you were, where you were each going with it and kinda understand. Like if they made that mistake, I could make that mistake.

The ability to have discussions with her classmates allowed Nancy, like El, to experience the material in a different way and to begin to truly make her own understanding of the material. Nancy also felt that the "confidence knock", as she described it, from being one of a few students who got a question wrong was something that she did not enjoy but appreciated that it was at least anonymous so that she felt the impact on her confidence internally rather than among her classmates.

Max's experience related to the opportunities for comparison with others focused mainly on "the common mistakes". She valued seeing how even when "lots of people got it right", the students were able see the mistakes and "make sure you don't make that mistake". The activities allowed her to see the common misconceptions and learn from other student's mistakes, which as Nancy explained "if they made that mistake, I could make that mistake". The common mistakes were also often given as possible solutions in the Google Form multiple choice questions, which provided opportunities for more discussion about the common mistakes.

Erica felt that the sharing of the whole class' answers allowed her to analyze whether or not she needed to "step up her game". She also felt that the discussions that followed often lead to a clearer understanding of the algorithm needed to solve the problems. She, like her classmates, was aware of the comparison that these activities allowed her to make with the rest of the class.

Robin shared El's appreciation for being able to "tap a friend" when she needed help and thought it was a major part of her enjoyment of these activities, especially for Desmos. Once again, the conflicting parts of the competitiveness that these activities stirred up was mentioned by Robin. She felt that sometimes seeing herself compared to others was good, but on the days where she did not do well, she would look around and see other classmates laughing and joking about "doing well" on the Next Day and felt frustrated. But, soon after this reflection, Robin also stated that comparing herself to others was "a good standard to see where you are, right, like how much you know." Although not specifically a part of this research project, Robin also brought up Kahoot and how much she enjoyed the competitiveness of that activity. She felt that this competitiveness and comparison "kinda kicked some kids in the butt or it [gave] people the confidence boost to keep doing what they're doing."

In both positive and negative ways, comparison and competitiveness were a common theme to these students' experiences with technology-based formative assessments. Almost to a student, these words created both positive and negative connotations often just sentences apart in the interviews. This duality was a common thread and an internal balancing act for the students that seemed to flip depending on the class. Although the negative experiences were common, they seemed to be more of a secondary reaction to the initial statement of the class comparison being the “kick in the butt” or “confidence boost” (as stated by Robin) that the student needed. Seeing other students struggling with the material also seemed to be comforting to the students in feeling that they were not alone in their struggles. Beyond the competitiveness, the ability to see other students’ solutions or have discussions about why solutions were right or wrong gave the students an opportunity to engage with the material in a way that was different than just listening to the teacher. Although these discussions would sometimes drift off task, the students did speak to the on task conversations they had and how this increased their enjoyment and understanding of the material. Their awareness of the ability to learn from their peers made it evident that this was a positive experience for encouraging students to engage with each other. This engagement took many forms, whether it be in small groups discussions about common errors, different solutions that gave the same answer, or as general conversations explaining they method or understanding to each other. Each allowed for rich conversations and opportunities to both teach and learn from each other.

Theme 3: “Not another worksheet” – Interactive and engaging activities.

The third theme that emerged from the interviews was that technology-based formative assessments provided an experience in math class that was “not another worksheet”, as stated by Nancy. As interactive and engaging activities, they gave the students an opportunity to use technology in the classroom in a way that made math more visual and tactile.

Joyce felt that these activities “turned into, like, a game” which made it “more likely that people will participate and get behind it, instead of getting lost and off track.” As a self-identified student “with ADHD, it’s easy to get distracted and the more, the more things where you kind of forced interaction, things that, like, you have to apply yourself, it’s much easier.” These activities were more “hands on” and “took a lot more than just doing it out of a textbook or something.” Since she always had something to be working on, she indicated she could not just sit back so these activities kept “everybody engaged and on track”. Part of this engagement was due to doing “something that was different and … more modern and kind of matches with our time.”

For El, as someone who enjoys math, “it was fun to, well I don’t, I don’t know if fun is the right word, but it was good to, like, change it up, and do something other than just, like, here’s another worksheet…” The use of digital technology alone was something that she found engaging, “where, like, something like a worksheet or a or a bubble sheet wouldn’t, wouldn’t have the same effect.”

Nancy, who identified herself as a “visual learner”, expressed her difficultly with math “when it was just numbers and equations. It [was] kind of tough. When you put it on and show, like, so you’d see, like, these two people did this and, like, this is why’s wrong ‘cause if you change this value, this is what it looks like on the graph.” For Nancy, the dynamic nature of the software allowed her to see the change in a graph when a parameter or variable was changed which “was huge”. Nancy also expressed that the use of technology “broke up the monotony a little bit, which, and again gave like a different kind of visual and understanding of what we were doing.” Instead of “here’s a worksheet, do it, here’s a worksheet, do it” Nancy wanted to be “able to talk it out and, you know, even just [learn] from each other” and these activities, especially Desmos, her preferred activity, allowed her to interact with others.

Max, a student currently attending university, mentioned that she still used Desmos in her studies. She valued the ability to “[play] around with all the values, like in a parabola, like the a-b-c values.” Instead of “memorizing, like, what each value means on a, like, from a piece of paper…” she could “punch in numbers and play around with it and see what each value does”.

Erica enjoyed the "interactiveness" of the activities. She found that these activities engaged her more than "just listening to, like, a teacher" because she felt like she was "putting in the work … while [she] was learning." She also appreciated the use of technology while completing the technology-based formative assessment and how she could access the Google Forms at home. She did not realize that she could also access the Desmos activities from home. These activities helped her to realize "that kind of integrated kind of math [takes] like, a boring thing into, hey, this can be interactive." One characteristic that engaged her as a learner that no other participants brought up was the ability to see her progress with these activities over time. She felt that this allowed her to see her growth as a learner and acted as a reminder of what she needed to review when preparing for tests or exams.

Robin, who only took Pre-Calculus 30S in my classroom, brought up how much of an effect the Desmos Polygraph activity had on her. She reminded me how she felt that she "wasn't good at math … like, not at all, but especially, especially when it came to graphs. Like [she] hated it, like [she] didn't get them…". But the matching activity allowed her to "familiarize something in a formula to the graph" and gave her an opportunity to engage with the material in a different way. She mentioned that being in a larger math class made it easy to "not pay attention for a class" but as soon as the iPad or other devices came out to complete an activity, it was exciting. Robin believed that these activities created "an environment where, it's like, it was almost kind of exciting to get iPads in math class, like you know, in the elementary kind of way. Like you're excited for it. So [she thought] it forced you to, to learn and it didn't seem so horrendous as sometimes math can."

Technology-based formative assessments allowed the students to both interact with each other to have mathematical conversations as well as to interact with the material in a different way than they were used to in a mathematics classroom. Although this was especially true for the Desmos activities, which appealed to the students because of the key dynamic features that immediately show how changes in an equation look on a graph, the Google Forms seemed to engage the students just by being something different and out of the normal flow of a mathematics classroom where they quickly received feedback which they could discuss and compare with their peers. Many of the students mentioned the glut of worksheets they received in mathematics classes and how difficult it was to make connections without the ability to see, for example, how a parameter changes the shape of a graph. Although their engagement experiences were diverse, as a whole Desmos and Google Forms provided an opportunity to engage with the material in a different way than they were used to.

Other Observations and Unique Responses

As discussed in the previous sections, the students did have some negative experiences within what were mostly positive themes. From feeling the negative effects of competition, even when anonymous, to not seeing complete solutions in Desmos or Google Forms, the technology-based formative assessments were not completely positive experiences. These negative experiences of the students were just as useful and allowed for more meaningful reflection for me as the teacher and the researcher in this situation, especially as further iterations of these assessments are developed. There was one observation in particular that emerged from three of the participants that I felt was important to mention. There were also a few comments and ideas from the participants that I, as both researcher and teacher, found applicable to this study and further iterations of these activities.

Homework versus technology-based formative assessments.

A thread that emerged from the interviews was a relationship between the students doing technology-based formative assessments in class and not doing homework because they knew they would be reviewing the material in class. According to El, "most students don't, including [herself], wouldn't, wouldn't usually, like, reread, [her] notes or reread whatever or go over anything" in between class, so the "quick, like, couple of questions just to, like, reinforce it was good to remember it in the long term." Although El didn't say directly state the two were related, she did mention that "getting that reinforcement without, you know, really having to do it on your own, it's, it's obviously helpful." So even though she heard me, as the teacher, suggest to reread notes and do practice questions on certain topics, she felt that this allowed her to review without having to do it on her own. Robin had a bit of a different view on why that review at home was not happening, but still related it to having these review activities to refresh her on the concepts. For her, "if you're busy, as you often are, with school and everything else" the next day allowed her to remember what she needed to know for class, "'[cause] I think a lot of people will go two days without doing math homework sometimes". In my opinion, these students generally do not have time to do math questions every night with their other curricular commitments and their extra-curricular activities. Students were often assigned two or three questions after each class to complete before the next class. Solutions were provided online for these questions and unless a specific question was raised, the questions were not formally gone through during class. Technology-based formative assessments, for at least three students, were a safety net for their understanding of the material because they did not always complete the work assigned outside of class. Although this could be taken with a negative perspective, it could be that this safety net was exactly what was needed by the students on the days where their other commitments took away from their mathematics studies. As a researcher, this connection between not completing homework because of the presence of technology-based formative assessments may be a possible topic for further study. As a teacher, this is something to consider in further iterations of how these activities are presented in the classroom.

Fresh stuff.

Another thread that was of interest to me as teacher and researcher revolved around the students' acknowledgement and appreciation for seeing me put in an effort to create new materials and not just, as Nancy says, handing out "another worksheet … recycled for the last 30 years…". Erica also commented on the material being new and modern, or as Nancy put it "it's, like, fresh stuff." For Nancy especially, she felt that these activities helped her to learn a little better and was a "change up [of] the way math was taught for [her]." As a teacher, this helped me to realize that students do recognize the effort being put in to create new material. Although this does not make the preparation take any less time, it is satisfying to know it is appreciated.

Engaging where they are at.

Robin and Joyce also both had similar positive experiences with how technology-based formative assessments were integrated into the classroom. They both appreciated the organization of being able to access the Google Forms Next Days with the rest of the material from that class in the Google Drive folder. When Robin moved on to a different section in Pre-Calculus 40S, she asked to be added to our Pre-Calculus 40S Google Drive folder to be able to complete the material for practice. According to Robin, "Like, I would have much preferred to [sic] being in your class you know, I like you as a guy, but a largely in part to this [referring to the class Google Drive folder and technology-based formative assessments]." She continued on saying:

> Like the whole course was different, right? Like it's not like we didn't use the textbook, we didn't have harder tests or easier tests or units or whatever. It was just, like, it was like, it felt like different. Like it wasn't pre-cal the same way I started to learn it like the year before. And, but then I also know kids who might've preferred to just use paper pencil from the textbook, whatever. But I think, like, for organization, for general enjoyment, for, for, like, comprehension for like the different, the different ways you can learn it, like different avenues you can take to learn the same thing. Like, I think it's, like, it was huge.

In her explanation for why the course was different, she mentions different ways and avenues of learning the same thing. This was in reference to the technology-based formative assessments.

Upon reflection, although not specifically mentioned by the students, another thread that appeared in multiple interviews was how these activities were able to meet students where they were at. Students who described themselves as enjoying math, being “visual” or “auditory” or “tactile” learners, being more interested in social science, or struggling with math all found these assessments to be powerful in giving them insight into their understanding of a concept or in the case of Desmos, deepening their understanding by allowing them to interact with the material in a different way. The students felt that these technology-based formative assessments provided them with a learning experience that was different than they have had otherwise. Although the study only reflects the views of six students, there was a wide spectrum of mathematical interests and ability.

Student attitudes towards technology.

One theme that emerged from a few of the students was how much they enjoyed using technology in the classroom and the lack of frustration that was expressed with using devices during class. Part of this result may be due to the time elapsed from their day to day interactions with the technology, but it was surprising to me that there was not a single complaint about the technology. There was a consistent feeling that these activities, and organization of the materials explained in the subsequent section, allowed the course to be, as Joyce described "a little more modernized". Both El and Erica felt the use of technology was "engaging" and "fantastic" as they are constantly around technology and Max appreciated the ability to pull up these activities on her phone, because "you always have your phone on you and you can practice with that." This meant students could quickly pull up the activities outside of class, either in the library or at home, and their learning could continue. The students also enjoyed the dynamic and visual representations that the technology provided them access to, whether it be the graphing and parameter exploration on Desmos or the ability to see whether their answer was correct immediately.

As the teacher in the classroom, I can attest to the lack of trouble I had when using both Google Forms and Desmos. Both sites can be set up in advance, are device agnostic, and my classes never experienced a site outage while using either tool. Another reason for the success of the devices in the classroom is that the school, as an independent school, was able to secure funding for a "larger than class size" set of iPads. This allowed for built in trouble shooting, as when one or two iPads were not charging properly, extra iPads were stored in the cart and students could exchange the drained device for one that was charged. The cart is also not widely used at the school, which meant it was usually available even at the last minute if needed. The school also has a consistent and stable wi-fi and the iPad cart was always picked up early to ensure the devices were charged and ready for class. Since the same devices were used every class, students became familiar with the devices and there was very little time wasted on set up or breakage. This is in contrast to the Roschelle et al. (2010) study where as much as seven minutes per class were wasted.

Google Drive organization.

Although not in the scope of focus for this research study and perhaps less focused on formative assessment, another minor theme that surfaced was how much the students appreciated the materials being organized in the class Google Drive folder so they were able to access the Google Form Next Day outside of class and then had the ability to review the notes on the subject or to watch a video to refresh their understanding. Joyce pointed out that she enjoyed how "everything was laid out … and planned, like, far in advance…". Robin appreciated being able to go back and review the material online and how the class "revolved around it [Google Drive]". Although the pedagogical considerations will be discussed in depth in Chapter 5, this was of note to me as the teacher, to provide the links to the Desmos activities in the Google Drive folder so students have access to everything in one place.

Summary

This chapter discussed the major and minor themes found while coding the student transcripts as well as addressing the first two research questions about how these technology-based formative assessments have affected the students' learning and the commonalities in the responses. The students felt that the technology-based formative assessments helped them to be better prepared for learning new material as well as giving them a chance to test their knowledge and understanding of material already covered. The learning experience provided by the technology-based formative assessments enriched their learning, whether it be from an internal motivation, classroom wide discussions engaged in during the activities, or one on one time with the teacher or the student. In general, they felt that the technology-based formative assessments provided them with a learning experience that engaged them, although as noted below in theme two, there were some attributes that provided for a negative learning experience. As for the commonalities, the participants indicated that technology-based formative assessments allowed them to get "back to math mode" and gave them an opportunity to take a personal check-in of their understanding, as well as reinforce and refresh the material. Second, the students felt that these assessments allowed them to have a comparison opportunity. This proved to be both enriching and disengaging for the students. Some students felt they were able to gain confidence by doing well or if they did poorly, they took it as an opportunity to take control of their learning. At the same time, some students felt that they became disengaged by their lack of success. Finally, students felt that these assessments allowed them to experience interactive and engaging activities, something other than yet another worksheet. A variety of minor themes and unique responses also emerged from the data, supplemented with reflections based on my own experiences as the classroom teacher, while creating and leading the technology-based formative assessments with the students.

Chapter 5: Discussion, Limitations, and Recommendations

The purpose of this study was to investigate the following research questions:

1. What are Pre-Calculus 30S and 40S students' reflections on how technology-based formative assessments have affected their learning?
2. What are the commonalities in these student's experiences?
3. How do the experiences of these students relate to Wiliam and Thompson's (2007) five key strategies of formative assessment?
4. What implications might these students' reflections have for how I approach technology-based formative assessments?

In order to address these questions, interviews were conducted (see Appendix A for the interview protocol) to examine the experiences of six former students from Pre-Calculus 30S and Pre-Calculus 40S mathematics classes. The previous chapter addressed the findings of the study as well as discussing the first two research questions. This chapter discusses findings from the final two research questions, the findings in relation to Wiliam and Thompson's (2007) five key strategies of formative assessment and the pedagogical considerations for my own classroom and for others moving forward, as well as the limitations of this study and the possibilities for future research.

Connections with Wiliam and Thompson's (2007) Five Key Strategies of Formative Assessment

As previously mentioned, Wiliam and Thompson (2007) developed five key strategies of formative assessment:

1. Clarifying, sharing, and understanding goals for learning and criteria for success with learners.
2. Engineering effective classrooms discussions, questions, activities, and tasks that elicit evidence of student's learning.
3. Providing feedback that moves learning forward.
4. Activating students as owners of their own learning.
5. Activating students as learning resources for one another.

These five strategies were also placed with Ramaprasad's (1983) three key processes in learning and teaching: establishing where the learners are in their learning, establishing where they are going and establishing what needs to be done to get them there to produce the framework shown in Figure 1.

In my analysis, a number of student comments and themes began to overlap with these five strategies, allowing me to make explicit connections from the students' experiences with Desmos and Google Forms to these strategies. It is important to note that during the interviews with the students used to collect data for this study, these five strategies were not mentioned. The questions were formed to capture the students' experiences while also trying to avoid an easy placement of answers into these categories. In the following section, the connections with the five key strategies and with other studies discussed in Chapter 2 will be presented. As this section address both the relationship between the student experiences and the implications for how I approach the technology-based formative assessments in the future, this reflection also provided an opportunity to begin to specifically address the fourth research question and look at what is lacking or needs improving in the assessments, mostly from a teacher implementation perspective.

Key strategy #1.

Clarifying, sharing, and understanding goals for learning and criteria for success with learners (Wiliam & Thompson, 2007) is an important base in helping students understand where they are going. Direct curriculum outcomes were never explicitly mentioned with these activities, and after reflection, I believe that this strategy is more than just giving students the curriculum outcomes. Students must be able to grasp what they need to know and how they can demonstrate that knowledge. According to Max, these activities allowed them to, "get shown what were the important things in the class" and make sure they had a solid understanding before moving on to the next topic, which often built on the last. Both Erica and Robin mentioned this idea of the new topic building on the last topic, and these formative assessments, by occurring on the day that the building was occurring, helped students to see the paths as connected and not just disjointed topics.

The second part of this strategy includes the criteria for success. One of the powerful outcomes of Desmos and Google Forms is that they allowed students to share their own paths to success with each other. Robin discussed the "different avenues you can take to the learn the same thing". The students enjoyed being able to see more than one path to a solution, not just looking at the teacher's answer key, and were able to see that math does not have a rigid and singular path to success. As Desmos allows the teacher to highlight and present different solutions, students were able to compare their work with multiple different, but correct, solutions. This is especially important for students who do not find mathematics easy to learn (NCTM, 2014; Wiliam, 2007). As a student who felt mathematics was “not her thing”, Joyce found that this comparison with other students’ work helped her to address misconceptions. She also felt that seeing other students struggle with material made her feel like she was not alone in not completing understanding each topic.

I believe both technology-based formative assessments addressed the requirements of this first strategy. Providing multiple paths of solutions online could give students the opportunity to see what excellence looks like. Clear links to these solutions online would allow the students to access the material outside of class, so the students who need more time to process the information would be able to access it at their own pace.

Key strategy #2.

The second key strategy, engineering effective classrooms discussions, questions, activities (Wiliam & Thompson, 2007), and tasks that elicit evidence of student’s learning, begins to move toward where the learner is at the current time. El mentioned how these activities “kind of gauge, like, where you’re at” and Joyce stated how “you can kind of see if you’re picking up the information or not”. Nancy felt that these “non graded progress checks” allowed her to assess her understanding and not get punished for not getting it totally correct. Each of these responses, in my opinion, meant that these assessments elicited evidence of the student’s learning. These also engineered effective classroom discussions, as Nancy said “being able to talk it out” helped her to see where she was and where she needed to go. This does not mean that the assessments were perfect assessment tools for that specific topic, but they did give both the students and me, as the teacher, the ability to see the general understanding of the class.

Students also indicated how the discussions they had while completing these assessments also helped them to be aware of their own understanding of the material. El's observation was how she would realize while listening to another student that she did understand the concept, just not how I had explained it. These discussions were powerful in helping the student know they were understanding the material or that they were behind. Nancy and Robin felt their ability to "talk it out" during technology-based formative assessments allowed them to interact with other students to connect mathematical ideas and make sense of the material, which did help to assess the range of mathematical activity in the class including mathematical processes such as reasoning, supporting the claims of Suurtamm et al. (2010).

El also found that the types of questions used addressed a base understanding of the material, which she was then able to use to identify areas of difficulty and made her more prepared for more difficult application questions. She found these "easier" questions helped her t "wrap her head around the idea of it" which made it easier to remember and apply later.

In my opinion, Desmos and Google Forms provided opportunities for effective discussions, questions and activities to elicit evidence of student's learning. Although the students did mention they felt the discussions that were initiated by these activities were meaningful, I believe I could have been more purposeful in my own discussions at a whole class level, modelling the type of discussions that the students could have to assess their understanding. There were also days where class had to continue on without the opportunity for these activities when a technology-based formative assessment was skipped because of the time needed to create the assessment. After seeing how important these were for the students and how powerful the feedback is for the teacher, I believe it is important to make time to create these assessments to provide these opportunities.

Key strategy #3.

Providing feedback that moves learning forward (Wiliam & Thompson, 2007) moves students into action. The feedback provided by Google Forms, at first glance, shares many characteristics with poor summative feedback. Students received a grade, with a right or wrong answer and no feedback beyond what the correct answer was. Left at that, the students seem to feel that it did not provide much in the way of detailed feedback the way a formative assessment should. However, as Nancy mentioned, what would happen after the entire class had finished is that the class would go through the solutions to discuss any questions. This led to discussions with me, as the teacher, and with their peers, moving the students into action. With Desmos, the feedback provided was much more formative in that it was immediate and included graphs or some sort of explanation with no final mark provided.

The feedback, according to the students, sent them on one of two paths. Either a poor result would send them to me, their peers or the class Google Drive folder for help or it would make them feel overwhelmed and make them want to quit. This comparison with others affected almost all the students in both the positive and negative ways according to their interviews and seemed to be related to how their day was going or their confidence level with that topic. Erica felt that when she did poorly on a technology-based formative assessment, her reaction was "hey, I need to work on this" and she would either look into the Google Drive folder or seek out my help. Robin found when she had just come from gym or lunch, she sometimes found it difficult to shift into a headspace where she could engage in mathematical thinking and then was frustrated by her result. But, she also felt that it would sometimes inspire her to seek the same resources as Erica when she knew that she had not given her best effort.

This dichotomy in the result of the comparison with others was a surprise to hear from so many of the students. The students did discuss the different options for them to address any poor results, such as extra help sessions, practice on Google Drive, or watching the topic video on Google Drive. El and Erica specifically said that they knew that they should stop by for extra help when they identified they were struggling with a topic after a technology-based formative assessment. Moving forward, for me as the teacher, it is incredibly important to address remind students of their options of actions to take if they did poorly to help continue to move their learning forward. Although many of the students interviewed mentioned they did know of the options, such as seeking extra help sessions or the materials on Google Drive, one further question would be to see how many of them actually engaged in this work. It is also crucial to remember the difficulty in addressing the needs of every student in a larger classroom, but also the importance of keeping frustrated students engaged and a part of the class. As stated by Pachler et al. (2010), the technology alone does not create moments of contingency, these are dependent on both the teachers' and learners' actions. Technology-based formative assessment requires a delicate balance of social, pedagogical and technological systems, and the students' remarks are evidence of this.

Key strategy #4.

Perhaps the strategy found to be most lacking in reaching its full potential was activating students as owners of their own learning. As discussed in the previous section many of the students, when faced with negative feedback about their understanding did move into addressing their lack of understanding by seeking out help from the available resources, a sign of them taking ownership for their learning. Many of the students mentioned how powerful they found the common mistakes that came up during discussions and how important they felt it was to learn from these mistakes, even if, as Nancy mentioned, they had not made the mistake in their own work. Pellegrino and Quellmalz (2010) also found this idea of common mistakes/similar pre-conceptions and found that properly designed technology-based formative assessments can identify these to both the student and teacher while moving the students toward individualized mastery learning.

Erica also mentioned how the technology-based formative assessments engaged her more than "just listening to like a teacher" and how they made her "put in the work" while she was working. Although El stated that "no one" ever rereads their notes at home after the teacher suggests it, she found that these activities, even though created by the teacher, did allow her to gauge where she was at. This was consistent among the students, that although they did not always use the full potential of being activated, they were more aware of the learning after these assessments.

Another interesting observation regarding this strategy was how the students viewed doing poorly on the assessments. El felt she could compare to the class and if everyone was doing poorly, it was the teacher's fault where Joyce felt if she saw the entire class was struggling that she took solace in the fact that it must be a difficult topic. Joyce's response seems to align to the strategy of students being activated as owners of their own learning, while El's response would go against taking ownership of her own learning.

This led me to reflect on students as owners of their own learning, and brought me to metacognition and self-regulation. As discussed by Clark (2012), "the objective of formative feedback is the deep involvement of students in meta-cognitive strategies such as personal goal-planning, monitoring, and reflection, which supports self-regulated learning" (p. 210). Self-regulated learners generate more internal feedback, which makes them more engaged and effortful (Clark, 2012). In my reflection of the class workflows and the student interviews, I believe encouraging students to think about the understanding and take control of their own learning could be encouraged much more when completing these activities. Building student confidence by continuously pointing out their successful strategies is an opportunity that has not been fully realized in my classroom. By utilizing the students more in full classroom conversations during these activities and allowing them to verbalize the processes used when solving, I hope the students have more opportunity to reflect and compare their own work. Perhaps more importantly, encouraging students to push themselves to be more independent and not rely on the teacher or another student to solve their problems the moment they run into one is another action to integrate into my classroom more often. This was seen in the student experiences as well, with El and Joyce having different experiences when seeing the entire class doing poorly on an activity. El saw it as the teacher's fault that the class did not do well, while Joyce took solace in the fact that it must be a difficult topic and that she shouldn't feel bad about no understanding. Joyce activated herself as a learner in this opportunity while El used it as an excuse. Although it was encouraged to be an active participant and learner, I believe a more consistent execution is important to help foster independence and metacognition.

Key strategy #5.

Activating students as learning resources for one another was one of the most commonly referenced strategies in my analysis of the interviews. The findings of the NCTM (2014) that formative assessments can encourage students to compare their own work with others was mirrored in this study. Both El and Nancy described the advantage of seeing the question done in different ways, especially when the solution provided by me did not make sense to them. As El commented "for certain things it's kinda hard to, like, understand it in the way … the teacher necessarily explains it, but the way somebody else might know it, then it might be easier." Robin discussed how the ability to "[tap] a friend" and be able to work through the Desmos activities with a friend was "huge" in how these activities engaged her as a learner.

Although the comparison with other students had both positive and negative ramifications as previously mentioned, many of the students discussed the benefits of being able to see solutions from another student's perspective. Both of the technology-based formative assessments provided opportunities to discuss the material with their peers, during the completion of the activities and the correcting period. Although not mentioned by the students, an observation from my perspective was that even on Google Forms Next Days, students would begin to have discussions amongst themselves about why and how they made mistakes on the multiple-choice questions. There were many conversations about the material with each other before the full class discussion about the solutions. This is not to say that some of these conversations did not happen during a class where there were no technology-based formative assessments, but these activities seemed to encourage the students to use each other as learning resources.

As discussed above, I believe the students experiences did fit in the five key strategies of formative assessment proposed by Wiliam and Thompson (2007). Technology-based formative assessments, although after reflection were not executed to their full potential, provided opportunities for students to engage in the five strategies and as such, "make decisions about the next steps in instruction that are likely to be better, or better founded, than the decisions they would have taken in the absence of the evidence that was elicited" (Black & Wiliam, 2009, p. 9).

Limitations

As a qualitative research study, this study carried the inherent risk of researcher bias (McMillan, 2012). Lincoln and Guba (1985) proposed a framework often used by qualitative researchers to establish trustworthiness within the limitations of a research study (Hoepfl, 1997).

In Chapter 3, I listed my personal biases regarding this research study. The purpose of this was twofold; to allow the audience to be aware of these biases and to make myself aware of my own biases as the research study took place. This is an "ongoing analytic process, rather than a single fixed event" (Patton, 2002, p. 485) and as previously mentioned, these biases were read prior to beginning the coding process.

Another attempt to reduce researcher bias was to discuss the coding process with a peer from the Masters program who had experience with coding and qualitative research in general. This "peer debriefing" was to attempt to address any personal bias that could have clouded the coding process that was not immediately obvious to the researcher (McMillan, 2012). Member-checking the data was also utilized by taking "data, analyses, interpretations, and conclusions back to the participants so that they can judge the accuracy and credibility of the account" (Creswell, 2007, p. 208).

Although a larger sample size may provide a better understanding of student experiences with technology-based formative assessment, the "meaningfulness and insights generated from qualitative inquiry have more to do with the information richness of the cases selected … than with sample size" (Patton, 2002, p. 245). Every attempt was made to include details and richness from each interview. Thick descriptive data was used "so that judgments about the degree of fit or similarity may be made by others who may wish to apply all or part of the findings elsewhere" (Schwandt, Lincoln, & Guba, 2007, p. 19).

Some other limitations to the study relate to which particular students decided to participate. Students were recruited from one graduating class at a single school using the school's online community. Some of the students may have had old email addresses still attached to the community and may have not received the initial recruitment letter. The recruitment was completed during the student's summer break from university and as such, students may have been travelling or busy with work during the recruitment window. As the study needed to progress forward, only a short window was available for recruiting and interviews. Another limitation of note, after the initial recruitment, only one student was initially available for an interview. This one student forwarded the letter on to the students of her graduating class for whom she had current contact information. This led to the five other students being recruited for the study. Although this may have further narrowed the possible pool of students, I was satisfied with the range of attitudes and abilities with mathematics. This study was also limited to students who took Pre-Calculus 30S and 40S, which should also be taken into account when reading the results of this study. For the most part, these were students who were planning on pursuing their education at a post-secondary institution. Finally, it should also be noted that all six students had a good working relationship with me as their teacher and in general, positive experiences in the classroom and so very different views may have been expressed by those students who had had less positive experiences.

While the audience for this research must decide for themselves if the findings and experiences are applicable to their context (McMillan, 2012), no claim of generalization is being made. While individual interviews were used to collect data, only one interview was conducted and was completed just under a year after course had completed. Since only one interview was conducted, an opportunity was missed to dig deeper into student experiences and responses.

Finally, to establish dependability and confirmability, a clear audit trail (Lincoln & Guba, 1985) was provided and was readily available for review by the thesis committee and any interested parties.

An in-depth description of the study methodology, conditions for the technology-based formative assessment and the data analysis was provided to allow others to fully situate themselves in the study. Peer-debriefing and member checking, which are methods suggested by Lincoln and Guba (1985) to ensure credibility, were used in an attempt to achieve credibility. The intent of this study was to give students a voice in their experience with technology-based formative assessment.

Desmos AND Google Forms

Finally, I offer some insight into why both Desmos and Google Forms were used together in this research study. There is some tension between being both the researcher and the educator in combining these two websites into one research study. As a researcher it may be more useful to examine each separately (also a possibility for further research), but as an educator these two tools were used in very similar ways with the same goal in mind; to allow students an opportunity to explore and review their understanding of the material and to evaluate, as a teacher, where the students stood both individually and for the class as a whole. In a sense, this was a success for both activities in my opinion, as both activities were referenced in all three themes. Doing a search of the direct quotes attributed to each theme in the interview transcripts, Google Forms was mentioned more than Desmos in the first theme, almost equally in the second theme (Desmos with a slight advantage) and Desmos more in the third (see Table 1). That being said, there were differences discussed between the two activities and the types of feedback they provided.

Table 1

Number of references to Google Forms and Desmos in each theme

	References to Google Forms	References to Desmos
Theme 1: "Back to math mode" – A Personal Check-In, a Refresh or Reinforcement and Deepening of Understanding	13	8
Theme Two: "A Kick in the Butt" or "Some Confidence" – A Comparison Opportunity	11	13
Theme Three: "Not Another Worksheet" – Interactive and Engaging Activities	6	12

After reflecting on this pattern, my opinion is that as a personal check in with the material, Google Forms was the more obvious choice to the students as it gave them a mark. Although this mark was not recorded in my gradebook, it is still a mark which is somewhat at odds with this being a formative assessment. Descriptive feedback is much more helpful for students which is noted in research (Black & Wiliam, 1998a; Hattie & Gan, 2011) as well as by the students. Nancy and Max both noted that it would be more useful to show why the answer is incorrect or to show common errors on specific questions. This could also be partially addressed by providing the students with full solutions to all the multiple-choice questions, giving them something with which to compare their final answer. As previous noted in Chapter 1, feedback is only one strategy of formative assessment and I believe what made these powerful formative assessments was not only the immediate feedback provided to me as the teacher, but also the discussions that followed and as the students mentioned, the fact that these did activate them as learners and learning resources for each other. Although this study did focus on the feedback from the technology-based formative assessments and the students' responses to the feedback received, it is important to note once again that this feedback was then used to inform learning for both the students and me, the teacher.

Desmos, on the other hand, does not provide a final mark but as Robin mentioned, the “questions were explained … with diagrams and drawings, not so much in words”. This once again led to discussions about specific slides and attention being brought to certain misconceptions or interesting ideas, filling the multiple strategies that are part of formative assessment.

For the comparison among students theme, there were two kinds of comparison taking place. There was the direct comparison of the end product (the mark in Google Forms or the graph/result in Desmos) as well as the comparison of ideas. Both of these activities, in my opinion, were successful in achieving both these types of comparisons. In the Google Forms, the students were able to compare their overall mark with the class (see Figure 4) as well as their answer on each specific question with the class (see Figure 5). In Desmos, when the results screen was shared, students were able to compare their graph to the other students’ graphs (see Figure 12) or their written answers to the other students’ response (see Figure 13).

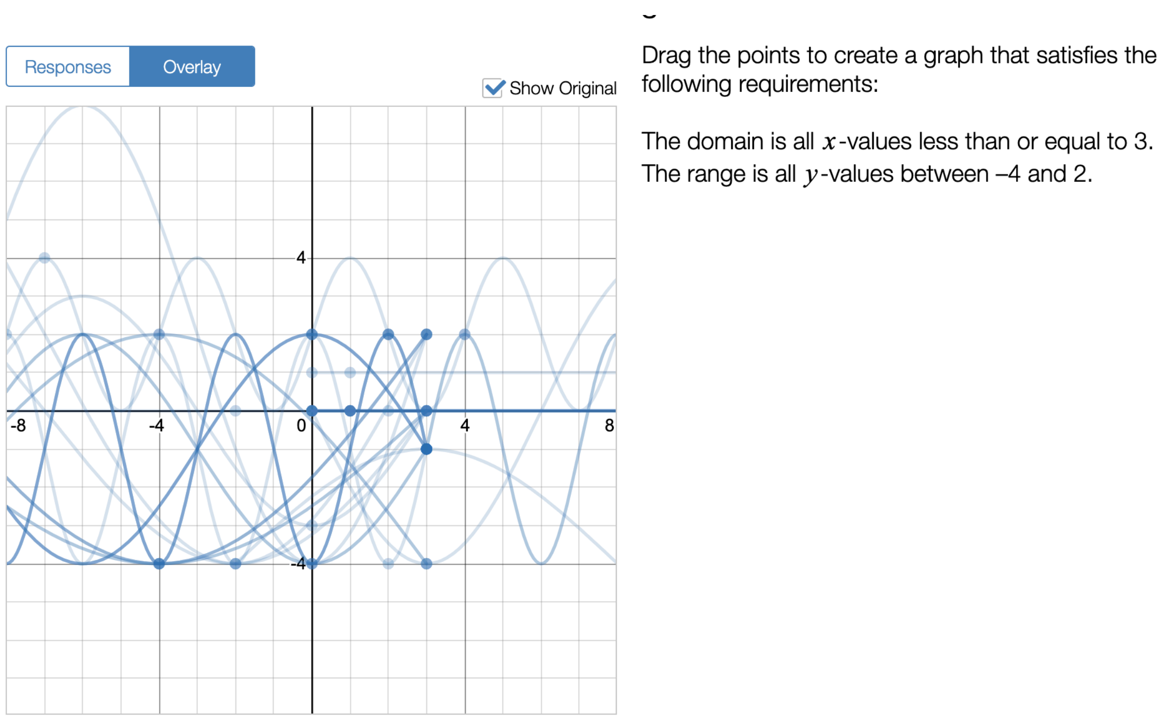


Figure 12. Overlay graph comparison

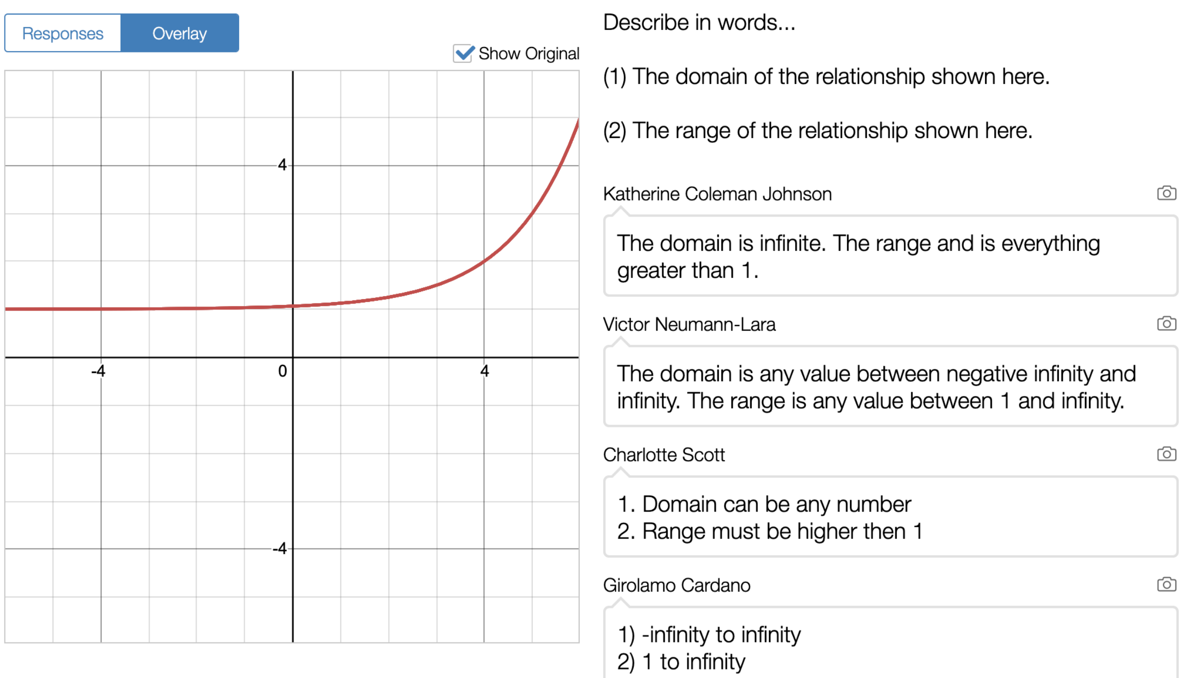


Figure 13. Student written response comparison

For both Google Forms and Desmos, this allowed students to directly compare their result with the rest of the class. Although this only was discussed a few times in the interviews, from my experience, I found that the comparison of ideas occurred in the mathematical discussions around the classroom. Students would look to their neighbours to discuss why they had gotten an answer wrong or would offer a deeper explanation of their solution on the screen. Even during the Google Form Next Days or Desmos activities that were supposed to be completed on their own, conversations would break out that were related to the questions. While my focus in this study is on the students' experience, I want to point out that this comparison of ideas was one of the most powerful benefits of these activities I experienced as a teacher.

Finally, for the engaging and interacting theme, Desmos was the more often mentioned activity. Once again, this does make sense given the visual and interactive opportunities provided by the Desmos activities. Desmos allows for dynamic sliders (see Figure 14) which multiple students mentioned helped them to connect the parameters to the effect each had on a graph. Although Google Forms are not as interactive, these Next Day activities did engage the students by giving them an opportunity to do something different and get immediate feedback on their understanding. This idea of completing an activity using technology was mentioned multiple times and, in my opinion, having a change from the usual class activities appeared to be a positive experience for the students. Although two of the students (Joyce and Nancy) preferred the feedback provided by the long answer paper and pencil Next Days, both still mentioned how they enjoyed the immediate feedback and the ability to compare their mark with the rest of the class.

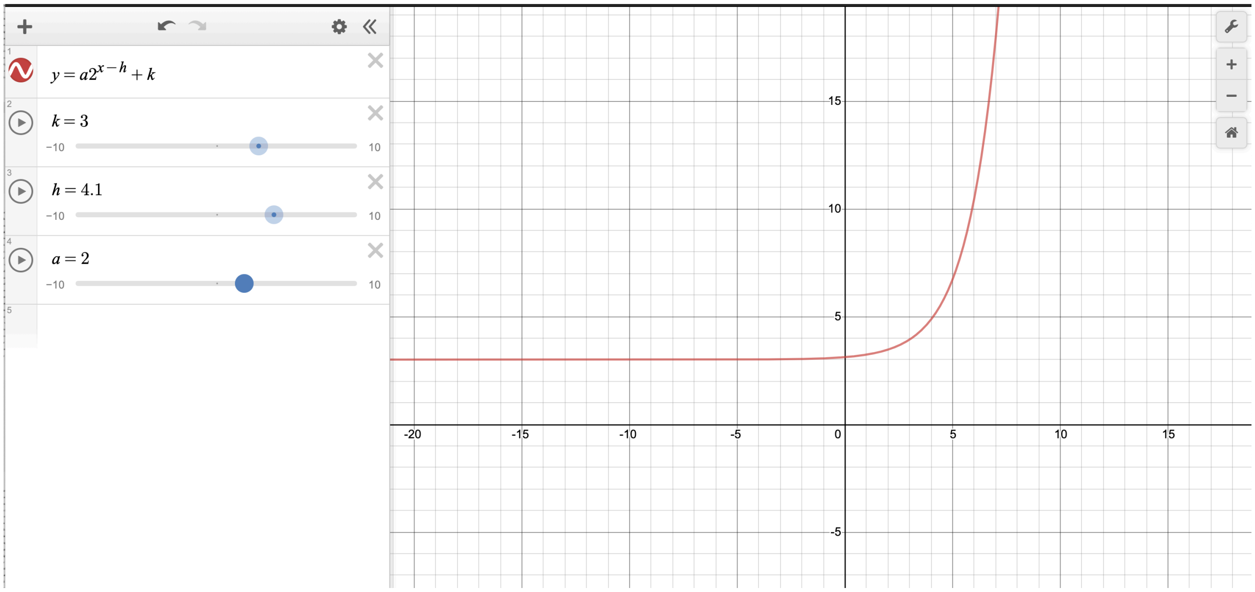


Figure 14. Dynamic sliders in Desmos activity

According to the students, these two activities used in conjunction with each other provided diverse experiences and engaging formative assessment. Between the two, the students were able to have opportunities to get a personal check in with the material, an opportunity to compare their understanding with their peers and engage and interact with the material in a different way.

Pedagogical Recommendations

Although the pedagogical considerations for my own teaching have been addressed throughout this chapter, the following section explores some of the pedagogical recommendations tied to the literature review, the students' perspectives and my own experience. In my interpretation of results of the student's experiences with Google Forms and Desmos as technology-based formative assessments, these activities provided an engaging and positive interaction that allowed the students to get a sense of their understanding of the material and then make decisions on what to do next with their learning. In many ways, as discussed above, these activities were a success. That being said, these activities are far from the "silver bullet" solution to the woes of students and teachers in the mathematics classroom. Part of what the students enjoyed about these activities is how different they were from what they were used to in a mathematics classroom and how they were used in conjunction with paper and pencil formative assessments. According to these students' experiences, a teacher should be using a multitude of different activities that give students different experiences with the material.

The current iterations and practices of implementing technology-based formative assessments are also far from their final or most effective form. As these websites continue to grow in functionality and as students make more recommendations for improvements, this will continue to be an ongoing process. Beckett et al. (2016), Suurtamm and Koch (2014) and McKnight et al. (2016) discussed the importance of collaborative professional development opportunities for teachers to develop their formative assessments. I have found as a teacher, professional development opportunities are most useful to me personally when there is time allowed to both share my personal experiences and listen to the experiences of others. This has allowed me to be continually improving and striving to push the limits of these assessments in the classroom. In my experience, this allows for the best development of the activities. Giving teachers the opportunity to act as both the teacher and the student in Google Forms and Desmos allows teachers to see possible trouble areas and gives a good working knowledge of the activities and websites and in my experience, made me comfortable with troubleshooting any issues the students may have. It also helped me to examine the activities more from a student's perspective and reiterated the importance of the student's voice in the classroom. Providing students with opportunities to give feedback on the classroom activities, whether it be in a formal research study such as this or course surveys or evaluations, is an important part of creating meaningful formative assessments.

McKnight et al. (2016) also discussed the importance technology support and infrastructure, as well as the importance of how the technology integration takes place. During this study, I found each of these ideas extremely important in the implementation of the technology-based formative assessments and the students mentioned their appreciation for how seamlessly the activities were interwoven in the classroom. Although I do not believe I completely took advantage of the opportunities presented, this integration allowed the students to become active learners and owners of their own learning. As such, I believe it is extremely important for teachers to properly integrate the technology in the classroom. The use of Google Drive to house the materials allowed for this to take place in my own classroom. In the future, integrating Desmos links into the Google Drive folders will allow students to completely access all materials in one place and assessment can become "richer, timelier, and more seamlessly interwoven with multiple aspects of curriculum and instruction" (Pellegrino & Quellmalz, 2010, p. 130).

A common negative experience noted during this study was the feeling of frustration when students compared themselves to others specifically or the class in general. As noted in Chapter 4, this frustration did lead to students taking action in some cases, but it is important to note the students who do not embrace this frustration as a call to action. As mentioned during the interviews, students who have little confidence in their mathematical abilities can sometimes disengage from the class when they feel overwhelmed by this frustration. I believe it is important to be aware of this possibility, and have a conversation with the student so they do not get lost for an entire class period. This is true for single students and for the class in general when the entire class does poorly on one of the technology-based formative assessments. It is important to have an activity to review the material and improve the confidence and understanding of the material when an activity shows that is necessary.

Another pedagogical concern previously noted is the feeling of students that no outside of class work is needed because of these formative assessments. Although homework is a contentious subject (Hallam & Rogers, 2018), in my experience due to schedule changes, extra curricular activities, and the limited amount of review that can be done during a 55 minute class, there are times when students may need to complete work outside of class. The feeling that the formative assessment activities could replace outside of class work requires awareness and reflection by the teacher.

Although initially only relevant to the Google Forms technology-based formative assessment, the lack of solutions to questions was a shortcoming raised by multiple students as well. The students also mentioned their appreciation in seeing "common mistakes" during these activities. Upon reflection, this led to a recommendation for both solutions and question creation. For the students to get the most out of the Google Form Next Day activities, it would be helpful to have fully worked out solutions attached which could be achieved by uploading an answer key to the class Google Drive folder. When creating the multiple-choice questions, it would be important to include "common mistake" distractor solutions, so students who have any misconceptions could identify them during these activities. Mentioning these common mistakes on the answer key would allow for students to be aware of them, even if they completed the question properly. In the opinion of the students, these common mistakes provided opportunities to review their own understanding of the material, even if they came to the correct solution when completing the assessment. They also mentioned how these mistakes allowed them to have conversations with each other where they were able to test the limits of their understanding and forced them to explain their reasoning for their solution. As such, creating meaningful questions that inspire conversations and show students their misconceptions of the material are important parts of these activities. Turning these conversations into meaningful action was a shortcoming in the use of these activities noted during this study. Students should become owners of their own learning (Wiliam & Thompson, 2007) during a formative assessment, and I believe by creating strong questions for both Desmos and Google Forms would encourage students to start down this path. This by no means needs to be completed by a single teacher; sharing best practices and questions during collaborative professional development sessions, as previously mentioned, would give teachers the best opportunities to create the best possible question sets.

Suggestions for Future Research

As technology-based formative assessments continue to undergo improvements and updates, new opportunities for research in this field change daily. In general, there has been a lack of research examining student experiences in formative assessment (Hattie & Gan, 2011). Specifically, studies where students are given a voice for the experiences with technology-based formative assessment are needed and one way this could be achieved is through replication of this study. Several suggestions for future research emerged specifically from this study.

First, in this study students made reference to both paper and Google Form Next Days, which are entrance slip activities. Their accounts of their experiences with the two formats of Next Days, although an attempt was made to be specific, were somewhat intertwined. How their experiences with each compared, what their preference for whether paper or electronic was the most useful to them and which served them better in improving their understanding are questions that emerged from this study.

Second, there are a multitude of websites beyond Google Forms and Desmos that have activities that could be considered technology-based formative assessments. Kahoot, Classkick and Nearpod are just a few of the possibilities that were not examined in this study. How the students experience these websites, how the websites compare to each other in terms of effectiveness and whether focusing on one or using a multitude of different sites are all possible topics that could be examined.

Finally, a third possibility to be explored is the placement of these activities during the class period and whether specific activities are more effective at the beginning, middle or end of a class would contribute to this research topic. We might also explore whether technology-based applications that are focused on mathematics and are dynamic and responsive such as Desmos are more effective than tools that are not specific to mathematics and also whether some specific content areas or mathematical processes can be particularly well supported with technology-based formative assessment as compared with other areas or processes.

Technology specific benefits of technology-based formative assessments

Part of the usefulness of formative assessment in my opinion lies in the number of different forms it can take in the classroom, in my opinion, whether it be paper and pencil, discussion based, or as in this study, technology based. During this study, there were five key characteristics of these assessments that were afforded specifically by using technology and would not have otherwise been possible. I believe these set technology-based formative assessments apart from the other types of formative assessment I have used in the classroom.

First was the ability to see the responses of the whole class in one clear and organized place. Both Google Forms and Desmos allowed me to see the results in a teacher dashboard (see Figures 4 and 11) as well as the response of each student. This allowed for opportunities to make decisions based on the overall results of the class as well as identify problem areas on specific questions, as the results for each question could be seen as well. In Desmos, it also gave the opportunity to highlight unique results and solutions anonymously to the entire class. Although these are not unique characteristics to technology-based formative assessments, the speed and ease of the collection and sharing was something that would not otherwise be possible.

A second characteristic was the immediacy of the feedback received. In both Google Drive and Desmos, students were able to see their results immediately after completing the assessment. Once again, this would be possible fairly quickly with a pencil and paper multiple choice assessment, but the time it would normally take to redistribute the assessments and then mark as a class was instead spent discussing the students' results and addressing any problem areas. The assessments were also completely anonymous and the students did not have to worry about other students knowing their results. This immediacy allowed us to address any misconceptions right away, just as they happened or allowed us to feel confident moving on to the next topic.

The third characteristic that was particular to the technology-based portion of the assessments was the dynamic nature of Desmos. Students were able to immediately see what effect changing a parameter in an equation meant to the nature of the graph as opposed to having to try to have conceive it theoretically in their mind. Once again, this is possible to do with pencil and paper, but adds a step to the process when trying to attach meaning to these concepts. Students are also able to complete many more changes to a graph than they would be able to without the technology. That is not to say that graphing by hand is not a useful task, but when used in this case it was more important to have the ability to make immediate connections graphically.

A fourth characteristic of the technology-based formative assessments specific to technology was the interactive and engaging nature of both tools. The students enjoyed doing something different than they were used to in mathematics class, allowing them to interact with the material and each other in a different way. The Polygraph activity allowed them to interact with their peers in a game-like fashion, while still being a meaningful opportunity to test their vocabulary on the material and still act as a formative assessment where feedback could be given to both individuals and the entire class. The students also found that they were able to interact with the material outside the classroom as well since the activities were being shared on the class Google Drive folder.

Finally, the unique visual representations of mathematics concepts in Desmos was a technology focused benefit of the technology-based formative assessments. Although Google Forms were useful to the students as a personal check in and as a comparison opportunity, Desmos is a tool specific to the mathematics classroom that allowed them to engage with the visual representations of the materials. This was important to the students who felt the ability to truly see math right in front of them, instead of just in the abstract, gave them an opportunity to seek deeper understanding. Desmos allows students to see equations, tables of values and graphs all at the same time and as already discussed, in an interactive and dynamic way. These visuals, in my opinion, were presented with a clean and visually pleasing aesthetic, with the ability to just touch the screen to find an intersection between two curves or move a slider to change a value.

Although the benefits to formative assessment exist outside of technology-based formative assessments, I believe the technology part of the assessments used in this study produce benefits not otherwise possible. The ability to immediately see the results in a teacher dashboard, or on the students screen, while still engaging in dynamic and interactive visual representations of mathematics allows for these to be powerful activities for a teacher to use in the mathematics classroom.

Conclusion

This chapter discussed how the experiences of students participating in technology-based formative assessments related to Wiliam and Thompson's (2007) five key strategies for formative assessment. These experiences were compared to the literature, the limitations of the study were discussed, and recommendations for both future iterations of the assessments and for future research were offered.

The purpose of this study was to gain an in-depth understanding of the experiences of students who complete technology-based formative assessments to better understand their learning experience. The main conclusions of this study reveals that each of the students had experiences that do align with the five key strategies of Wiliam and Thompson (2007). The students were activated as owners of their learning, engaging in discussions with their peers and with me to better understand the material. They sought out the many resources available to them to address any shortcomings they felt they had with the material. The students engaged with dynamic and interactive activities, as well as each other in small group and class-wide discussions. This implies that the technology-based formative assessments can be called just that, formative assessments. Although there were experiences that did not align with the strategies, these were changes that noted to be made to the implementation of the assessments used in this study or at the very least, experiences teachers should be aware of when implementing these in the classroom. The technology-based formative assessments provide meaningful formative assessment experiences for students in the mathematics classroom while providing the teacher with rich data with which to inform their instructional choices. Perhaps most importantly, this study provides me with a reminder of how important it is to listen to the students' voices. Their experiences provided me with both the strengths and weakness of these activities, some of which I would not have identified without listening to them. It is their voice I hope I was able to serve in this study, giving their experiences a platform to be heard.

References

Azevedo, A., & Azevedo, J. (2019). *Handbook of research on E-assessment in higher education*.

Bälter, O., Enström, E., & Klingenberg, B. (2013). The effect of short formative diagnostic web quizzes with minimal feedback. *Computers & Education, 60*(1), 234-242. doi:http://dx.doi.org/10.1016/j.compedu.2012.08.014

Beatty, I. D., & Gerace, W. J. (2009). Technology-Enhanced Formative Assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology, 18*(2), 146-162. doi:10.1007/s10956-008-9140-4

Beckett, D., Volante, L., & Drake, S. (2016). Formative assessment: Bridging the research - practice divide. *Education Canada, 56*(2). Retrieved from http://www.cea-ace.ca/education-canada/article/formative-assessment-bridging-research-practice-divide

Bell, B., & Cowie, B. (1999). A model of formative assessment in science education. *Assessment in Education: Principles, Policy & Practice, 6*(1), 101-116. doi:10.1080/09695949993026

Bennet, R. E. (2011). Formative assessment: a critical review. *Assessment in Education: Principles, Policy & Practice, 18*(1), 5-25. doi:10.1080/0969594X.2010.513678

Black, P., Harrison, C., Marshall, B., & Wiliam, D. (2003). *Assessment for learning: Putting it into practice*. Maidenhead: McGraw-Hill Education.

Black, P., & Wiliam, D. (1998a). Assessment and Classroom Learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7-74. doi:10.1080/0969595980050102

Black, P., & Wiliam, D. (1998b). Inside the black box: Raising standards through classroom assessment. *The Phi Delta Kappan, 80*(2), 139-148. Retrieved from http://www.jstor.org/stable/20439383

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability, 21*(1), 5-31. doi:10.1007/s11092-008-9068-5

Bloom, B. S., Hastings, J. T., & Madaus, G. F. (1971). Handbook on formative and summative evaluation of student learning.

Boaler, J. (2002). *Experiencing school mathematics: Traditional and reform approaches to teaching and their impact on student Llearning, revised and expanded edition* (Vol. Rev. and expanded ed). Mahwah, N.J.: Routledge.

Clark, I. (2012). Formative assessment: Assessment is for self-regulated learning. *Educational Psychology Review, 24*(2), 205-249. doi:10.1007/s10648-011-9191-6

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches* (2nd ed.. ed.). Thousand Oaks: Thousand Oaks : Sage Publications.

desmos. (2019). Polygraph: Parabolas. Retrieved from https://teacher.desmos.com/polygraph-parabolas

Hallam, S., & Rogers, L. (2018). *Homework : The evidence (Fully revised and expanded edition.)*. London: UCL Institute of Education Press.

The handbook for embedded formative assessment. (2018). Bloomington, IN: Solution Tree Press, a division of Solution Tree.

Hattie, J. (2011). *Visible learning for teachers: Maximizing impact on learning*. London: Routledge.

Hattie, J., & Gan, G. (2011). Instruction based on feedback. In R. E. Mayer & P. A. Alexander (Eds.), *Handbook of research on learning and instruction* (pp. 249-271). New York: New York : Routledge.

Hechter, R. P., & Vermette, L. A. (2013). Technology integration in K-12 science classrooms: An analysis of barriers and implications. *Themes in Science and Technology Education, 6*(2), 73-90.

Heritage, M. (2007). Formative assessment: What do teachers need to know and do? *Phi Delta Kappan, 89*(2), 140-145. doi:10.1177/003172170708900210

Heritage, M. (2010). *Formative assessment: Making it happen in the classroom*. Retrieved from [Kindle DX version]

Hoepfl, M. C. (1997). Choosing Qualitative Research: A Primer for Technology Education Researchers. *Journal of Technology Education, 9*(1), 47-63. doi:doi.org/10.21061/jte.v9i1.a.4

Lee, H., Feldman, A., & Beatty, I. D. (2012). Factors that Affect Science and Mathematics Teachers' Initial Implementation of Technology-Enhanced Formative Assessment Using a Classroom Response System. *Journal of Science Education and Technology, 21*(5), 523-539. doi:10.1007/s10956-011-9344-x

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, Calif.

Newbury Park, Calif.: Beverly Hills, Calif. : Sage Publications.

Looney, J. (2011). *Integrating formative and summative assessment*: OECD Publishing.

Manitoba Education, Citizenship and Youth,,. (2006). Rethinking Classroom Assessment with Purpose in Mind.

Manitoba Education and Advanced Learning. (2014). *Grade 9 to 12 mathematics [electronic document] : Manitoba curriculum framework of outcomes*. Retrieved from https://www.edu.gov.mb.ca/k12/cur/math/framework_9-12/full_doc.pdf

McIntosh, M. E. (1997). Formative assessment in mathematics. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 71*(2), 92-96. doi:10.1080/00098659709599333

McKnight, K., O'Malley, K., Ruzic, R., Horsley, M. K., Franey, J. J., & Bassett, K. (2016). Teaching in a digital age: How dducators use technology to improve student learning. *Journal of Research on Technology in Education, 48*(3), 194-211. doi:10.1080/15391523.2016.1175856

McMillan, J. H. (2012). *Educational research: Fundamentals for the consumer (6th ed)*. Boston, MA: Pearson Education, Inc.

Messineo, M., & DeOllos, I. Y. (2005). Are we assuming too much?: Exploring students' perceptions of their computer competence. *College Teaching, 53*(2), 50-56. doi:10.3200/CTCH.53.2.50-56

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers college record, 108*(6), 1017.

Moustakas, C. (1994). *Phenomenological research methods*. doi:10.4135/9781412995658

NCTM. (2014). *Principles to actions: Ensuring mathematical success for all*. Reston, VA: NCTM.

NMAP. (2008). The final report of the National Mathematics Advisory Panel. Retrieved from https://www2.ed.gov/about/bdscomm/list/mathpanel/report/final-report.pdf

Ontario Ministry of Education. (2010). Growing success : Assessment, evaluation, and reporting in Ontario schools. Retrieved from http://www.edu.gov.on.ca/eng/policyfunding/growsuccess.pdf

Pachler, N., Daly, C., Mor, Y., & Mellar, H. (2010). Formative e-assessment: practitioner cases. *Computers & Education, 54*(3), 715-721. doi:http://dx.doi.org/10.1016/j.compedu.2009.09.032

Patton, M. Q. (2002). *Qualitative research & evaluation methods* (3rd ed.. ed.). Thousand Oaks, Calif.: Thousand Oaks, Calif. : Sage Publications.

Pellegrino, J. W., & Quellmalz, E. S. (2010). Perspectives on the integration of technology and assessment. *Journal of Research on Technology in Education, 43*(2), 119-134. doi:10.1080/15391523.2010.10782565

Ramaprasad, A. (1983). On the definition of feedback. *Behavioral Science, 28*(1), 4. Retrieved from http://uml.idm.oclc.org/login?url=http://search.proquest.com/docview/1301271301?accountid=14569

http://primo-pmtna01.hosted.exlibrisgroup.com/openurl/01UMB_INST/umb_services_page? ?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Apao&atitle=On+the+Definition+of+Feedback&title=Behavioral+Science&issn=00057940&date=1983-01-01&volume=28&issue=1&spage=4&au=Ramaprasad%2C+Arkalgud&isbn=&jtitle=Behavioral+Science&btitle=&rft_id=info:eric/&rft_id=info:doi/

Roschelle, J., Abrahamson, L., & Penuel, B. (2004). *Integrating classroom network technology and learning theory to improve classroom science learning: a literature synthesis*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego.

Roschelle, J., Rafanan, K., Bhanot, R., Estrella, G., Penuel, B., Nussbaum, M., & Claro, S. (2010). Scaffolding group explanation and feedback with handheld technology: Impact on students' mathematics learning. *Educational Technology Research and Development, 58*(4), 399-419. doi:10.1007/s11423-009-9142-9

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. *Instructional Science, 18*(2), 119-144. Retrieved from http://www.jstor.org/stable/23369143

Saldaña, J. (2016). *The coding manual for qualitative researchers*.

Schroeder, L. B., & Dorn, B. (2016). Enabling and integrating online formative assessment in a flipped calculus course. *Primus*. doi:dx.doi.org/10.1080/10511970.2015.1050619

Schwandt, T. A., Lincoln, Y. S., & Guba, E. G. (2007). Judging interpretations: But is it rigorous? trustworthiness and authenticity in naturalistic evaluation. *New Directions for Evaluation, 2007*(114), 11-25. doi:10.1002/ev.223

Scriven, M. (1967). The methodology of evaluation. In R. M. Gagné, M. Scriven, & R. W. Tyler (Eds.), *Perspectives of curriculum evaluation* (pp. 39-83). Chicago: Chicago : Rand McNally.

Shepard, L. A. (2000). The Role of Assessment in a Learning Culture. *Educational Researcher, 29*(7), 4–14. doi:https://doi.org/10.3102/0013189X029007004

Shirley, M. L., & Irving, K. E. (2015). Connected classroom technology facilitates multiple components of formative assessment practice. *Journal of Science Education and Technology, 24*(1), 56-68. doi:10.1007/s10956-014-9520-x

Stiggins, R. (2005). From formative assessment to assessment for learning: A path to success in standards-based schools. *The Phi Delta Kappan, 87*(4), 324-328. Retrieved from http://www.jstor.org/stable/20441998

Stödberg, U. (2012). A research review of e-assessment. *Assessment & Evaluation in Higher Education, 37*(5), 591-604. doi:10.1080/02602938.2011.557496

Suurtamm, C., Koch, M., & Arden, A. (2010). Teachers' assessment practices in mathematics: classrooms in the context of reform. *Assessment in Education: Principles, Policy & Practice, 17*(4), 399-417. doi:10.1080/0969594X.2010.497469

Suurtamm, C., & Koch, M. J. (2014). Navigating dilemmas in transforming assessment practices: experiences of mathematics teachers in Ontario, Canada. *Educational Assessment, Evaluation and Accountability, 26*(3), 263-287. doi:10.1007/s11092-014-9195-0

Swallow, M. (2015). The year-two decline: Exploring the incremental experiences of a 1:1 technology initiative. *Journal of Research on Technology in Education, 47*(2), 122-137. doi:10.1080/15391523.2015.999641

Vygotsky, L. S. (1978). *Mind in society: the development of higher psychological processes*. Cambridge: Cambridge : Harvard University Press.

Wiliam, D. (2007). Keeping learning on track: Classroom assessment and the regulation of learning. In F. K. Lester Jr. (Ed.), *Second Handbook of Research on Mathematics Teaching and Learning* (pp. 1053-1098). Charlotte, NC: Information Age Publishing.

Wiliam, D. (2010). An integrative summary of the research literature and implications for a new theory of formative assessment. In H. L. Andrade & G. J. Cizek (Eds.), *Handbook of formative assessment* (pp. 18-40). New York: Routledge.

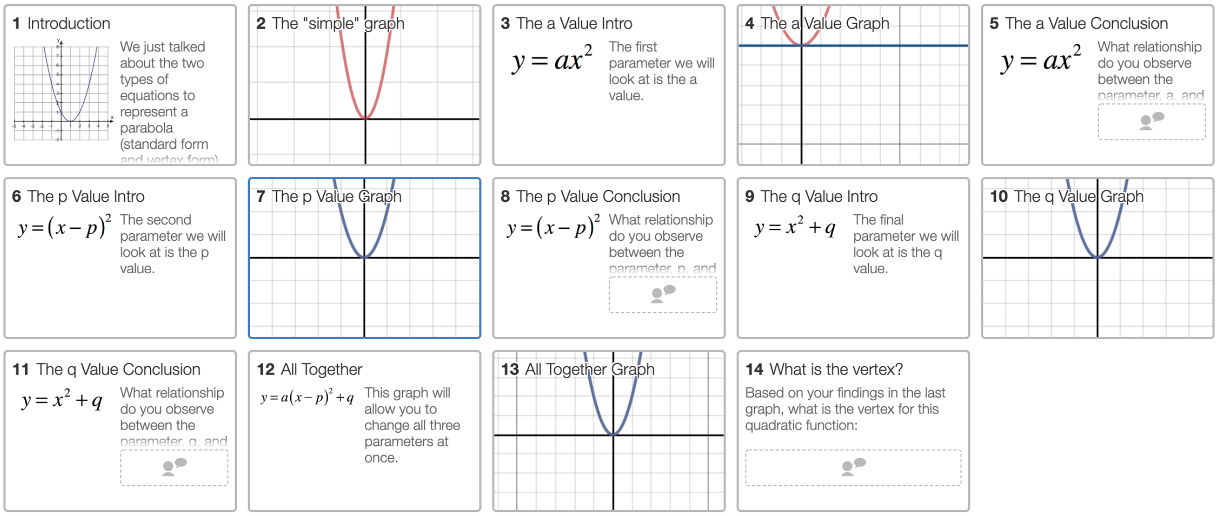
Wiliam, D., & Thompson, M. (2007). Integrating assessment with instruction: What will it take to make it work? In C. A. Dwyer (Ed.), *The future of assessment: shaping teaching and learning*. Mahwah, NJ: Lawrence Erlbaum Associates.

Yin, R. K. (2011). *Qualitative research from start to finish*. New York: New York : Guilford Press.

Appendix A: Interview Protocol with Sample Activities

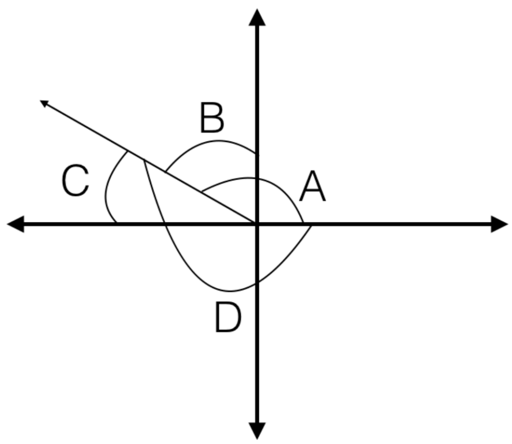
1. In our Grade 12 Pre-Calculus course, we used Desmos and Google Forms as learning tools. Here are some samples of the types of activities we did with these tools. (see next page for sample Desmos and Google Forms technology-based formative assessments created by the researcher)
2. Describe your experience with Google Forms.
    a. Would you say your experience with this tool was positive or negative overall?
3. Describe your experience with Desmos.
    a. Would you say your experience with this tool was positive or negative overall?
4. Tell me about how these tools were integrated into the classroom learning environment in your experience.
5. How did you feel these tools affected your learning?
6. How did these tools engage you as a learner?
7. In your experience, what are the most beneficial parts of these tools?
8. In your experience, what is lacking or didn't serve you as a learner with these tools?
9. How did you feel about the feedback received from these tools? What could be done to make the feedback more useful?
10. How were these tools different than other tools you have used?

Desmos Activity:



Google Forms Activity:

3. Which of the following represents the reference angle for an angle of 160° in standard position? * 1 point



- A
- B
- C
- D

4. The reference angle for 30° is * 1 point

- 330°
- -330°
- 150°
- 30°

5. The reference angle for 250° is * 1 point

- 20°
- 70°
- 250°
- -110°

6. The reference angle family for 130° is * 1 point

- 60°, 130°, 240°, 300°
- 60°, 130°, 270°, 300°
- 50°, 130°, 230°, 310°
- 50°, 130°, 220°, 310°

Appendix B: Letter to Principal

UNIVERSITY OF MANITOBA | Faculty of Education
Department of Curriculum, Teaching and Learning

230 Education Building
University of Manitoba
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-9014
Fax (204) 474-7550

From: Jason Hurton; Graduate student at the University of Manitoba; Faculty of Education

Email: umhurton@myumanitoba.ca

To: [Principal's name]
[School name]
[School address]

Date: [Date]

Re: Request to recruit former students for a research project
Technology-based Formative Assessment: Student Perceptions in Pre-Calculus Mathematics

Dear Mr. [NAME],

As you know, I am currently a graduate student at the University of Manitoba in the Faculty of Education in Curriculum, Teaching and Learning. I am in the process of completing a Master's Thesis project on the experiences of my former students using technology-based formative assessment in the Pre-Calculus 40S course.

My thesis proposal has been approved by my advisory committee in the Faculty of Education at the University of Manitoba and the Education and Nursing Research and Ethics Board at the University of Manitoba has granted me permission to proceed with this research study. I am contacting you for permission to contact my former students on the school's online community to ask if they would consider being a participant in this research project. There is a form at the end of this letter that you can sign if you choose to grant me permission to move ahead with this study.

Below, I present a summary of the research study, its purpose, proposed data collection methods, and other important information for your decision-making process.

Summary of Research

The purpose of this study is to gain an in-depth understanding of the experiences of students who complete technology-based formative assessments to better understand their learning experience using a phenomenological approach. First and foremost, this will give insight into whether my students feel that there are any benefits to their own learning from these assessments. Their insight will contribute to future iterations of these assessments, creating more meaningful assessments for students from the weaknesses they identify. Second, I believe from my own experience that students are often forgotten as instructional decision makers. As such, this study contributes to giving my students a voice as an important part of the formative assessment process. The central research question which will frame my research is: What is the experience of mathematics students who participate in technology-based formative assessments?

The participants of this student are six to ten former students who have experienced technology-based formative assessments in my classroom. Each participant will participate in an initial interview, followed by a follow-up interview. The schedule for these activities will be arranged and established between myself and each participating former student.

In conclusion, each section of this study will take approximately:
i. Scheduling initial interviews and previewing interview protocol (approximately 20 minutes)
ii. Initial interview (approximately 60 minutes)
iii. Prereading transcripts and field notes for follow-up interview (approximately 60 minutes)
iv. Follow-up interview (if necessary) (approximately 30 minutes)

The total time commitment for the former students to participate in this study is approximately three hours (170 minutes).

Participation in this research project is completely voluntary and participants may withdraw from the study at any time with no reason and with no prejudice or consequence. My advisor, Dr. Richard Hechter and I, will be the only people that will know the names of the participants and will guarantee the confidentiality of all of the participants. My advisor and I will be the only people that will access to identifying information. My committee members, Dr. Martha Koch and Dr. Jerry Ameis, will have access to non-identifiable data as they will be reading drafts of my work. My advisor and I will be the only people with access to raw audio data, and I will ensure that all identifiers (such as student names and the name of the school) will be omitted or replaced by pseudonyms during the transcribing. The usual protocols for protecting the security of data including its eventual destruction will be followed, and the participants will be fully informed about these procedures. All data associated with this study will be destroyed two years after my thesis completion and graduation; no later than December 2021.

There is minimal risk to the participants in this study. If an unexpected disclosure arises, I am guided by the Manitoba Teacher Society Code of Ethics and will report the allegations to the appropriate authorities.

I am available to meet with you in person to explain the research in more details or answer any questions or concerns you may have regarding this study. You can also contact me through phone and/or email provided above. You may also contact my advisor, Dr. Richard Hechter, at the University of Manitoba if you have any questions or concerns regarding this study. His telephone number is 204-474-9013 and his email address is richard.hechter@umanitoba.ca. You may also contact the Human Ethics Coordinator at the University of Manitoba if you have further questions at 204-474-7122 or humanethics@umanitoba.ca.

Your signature on this form indicates that you have understood to your satisfaction the information regarding giving permission for the former students to be contacted. In no way does this waive your legal rights nor release the researcher from their legal and professional responsibilities. The research participants are free to withdraw from participation in this study at any time, without prejudice or consequence.

The University of Manitoba may look at the research records to see that the research is being done in a safe and proper way. This research has been approved by the Nursing and Education Research Ethics Committee. If you have any concerns or complaints about this project you may contact the principal investigator (information provided above) or the Human Ethics Coordinator at the University of Manitoba using the contact information provided above.

A copy of this consent form has been given to you to keep for your records and reference.

With your permission, I would like to contact the former students to invite them to participate in this research.

Thank you for your consideration.

Sincerely,

[Signature]
Jason Hurton

Appendix C: Initial Recruitment Letter

UNIVERSITY OF MANITOBA | Faculty of Education
Department of Curriculum, Teaching and Learning

230 Education Building
University of Manitoba
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-9014
Fax (204) 474-7550

From: Jason Hurton; Graduate student at the University of Manitoba; Faculty of Education

Email: umhurton@myumanitoba.ca

To: Former Pre-Calculus 40S students

Date: [Date]

Re: Request for participation in a research project
Technology-based Formative Assessment: Student Perceptions in Pre-Calculus Mathematics

Dear former Pre-Calculus 40S student,

As you may know, I am currently a graduate student at the University of Manitoba in the Faculty of Education in Curriculum, Teaching and Learning. I am in the process of completing a Master's Thesis project on the experiences of my former students using technology-based formative assessment in the Pre-Calculus 40S course.

My thesis proposal has been approved by my advisory committee in the Faculty of Education at the University of Manitoba. The Education and Nursing Research and Ethics Board at the University of Manitoba has granted me permission to proceed with this research study. I have recently completed the procedures required for research and ethics approval at [Name of school], and I have received permission from [Name of school principal] to contact the former students to participate in this study.

I would like to invite you to participate in this research project. The purpose of this study is to gain an in-depth understanding of the experiences of students who complete technology-based formative assessments to better understand their learning experience.

Please note that the school principal does not know your identity, although this might become known in the course of carrying out the study. I assure you that there are no consequences or future penalties if you decide to not take part in this study or for being honest about your experiences completing the technology-based formative assessments. Negative experiences will just serve to further the development and inform future decision making processes around these assessments.

Below, I present a brief summary of the research study including its purpose and data collection methods so that you are fully informed. If you choose to participate in this study as a former Pre-Calculus 40S student, please read the information in the consent form attached.

Summary of Research

The purpose of this study is to gain an in-depth understanding of the experiences of students who complete technology-based formative assessments to better understand their learning experience using a phenomenological approach. First and foremost, this will give insight into whether my former students feel that there are any benefits to their own learning from these assessments. Their insight will contribute to future iterations of these assessments, creating more meaningful assessments for students from the weaknesses they identify. Second, I believe from my own experience that students are often forgotten as instructional decision makers. As such, this study contributes to giving my students a voice as an important part of the formative assessment process. The central research question which will frame my research is: What is the experience of mathematics students who participate in technology-based formative assessments?

The data collection for this project will take place on through an initial interviews then through an optional follow-up interview. Both the initial interview and the optional follow-up interview will take place on mutually agreed locations and time that are the most convenient for you and make the best effort to ensure your privacy. If you do not have a preference for where the interview could be held, the interviews will take place in the private conference room at the school. The interviews will be held outside normal class time at the school to best provide privacy for you, but no guarantee of complete privacy can be made. If this arrangement is not agreeable, alternate arrangements/locations will be made available to better maintain your privacy or you may withdraw from the research study. The purpose of the follow-up interview is to provide an opportunity for you to offer further insight into your comments and reflections on your experiences with the technology-based formative assessments. If you feel there are no revisions to be made after reviewing the transcripts and the researcher does not require any further clarifications, there may be no need for follow-up interview.

The approximate time commitment to participate in this study includes:
i. Scheduling initial interviews and reviewing interview protocol (approximately 20 minutes)
ii. Initial interview (approximately 60 minutes)
iii. Prereading transcripts and field notes for follow-up interview (approximately 60 minutes)
iv. Follow-up interview (if necessary) (approximately 30 minutes)

The total time commitment to participate in this study is approximately three hours (170 minutes). The initial transcripts will be provided to you within 7 days of the interview and changes/revisions can be made to your transcript up to one month following the interview. The follow-up interview used to clarify or further explore your responses in the first interview.

I would greatly appreciate it if you were to consider my request to be a participant in this research, whether you had positive or negative experiences with the course or the technology-based formative assessments. I have attached a consent form for you to complete and sign should you agree to participate.

I would be glad to meet with you in person to explain the research in more detail or answer any questions or concerns you may have regarding this study. You can also contact me through phone and email (provided above). You may also contact my advisor, Dr. Richard Hechter, at the University of Manitoba if you have any questions or concerns regarding this study. His telephone number is 204-474-9013 and his email address is richard.hechter@umanitoba.ca. You may also contact the Human Ethics Coordinator at the University of Manitoba if you have further questions at 204-474-7122 or humanethics@umanitoba.ca.

Thank you very much.
Sincerely,

[Signature]
Jason Hurton

Appendix D: Informed Consent Form

UNIVERSITY OF MANITOBA | Faculty of Education
Department of Curriculum, Teaching and Learning

230 Education Building
University of Manitoba
Winnipeg, Manitoba
Canada R3T 2N2
Telephone (204) 474-9014
Fax (204) 474-7550

From: Jason Hurton; Graduate student at the University of Manitoba; Faculty of Education

Email: umhurton@myumanitoba.ca

To: [Former Pre-Calculus 40S student]

Date: [Date]

Re: Consent Letter for research project
Technology-based Formative Assessment: Student Perceptions in Pre-Calculus Mathematics

Dear Mr. [NAME],

I am a Master's of Education student in the department of Curriculum, Learning and Teaching at the University of Manitoba and the principal investigator in a research project that explores students' perceptions of if and how technology-based formative assessments contribute to their own learning. I would like to request your consent for participation in this research project and to collect data from you.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The purpose of this study is to gain an in-depth understanding of the experiences of students who complete technology-based formative assessments to better understand their learning experience using a phenomenological approach. First and foremost, this will give insight into whether my former students feel that there are any benefits to their own learning from these assessments. Their insight will contribute to future iterations of these assessments, creating more meaningful assessments for students from the weaknesses they identify. Second, I believe from my own experience that students are often forgotten as instructional decision makers. As such, this study contributes to giving my students a voice as an important part of the formative assessment process. The central research question which will frame my research is: What is the experience of mathematics students who participate in technology-based formative assessments?

The data collection for this project will take place on through interviews and follow-up interviews. Interviews will take place on mutually agreed days and times, arranged with each participant to best ensure privacy. If you do not have a preference for where the interview could be held, the interviews will take place in the private conference room at the school. The interviews will be held outside normal class time at the school to best provide privacy for you, but no guarantee of complete privacy can be made. If this arrangement is not agreeable, alternate arrangements/locations will be made available to better maintain your privacy or you may withdraw from the research study. If you feel there are no revisions to be made after reviewing the transcripts and the researcher does not require any further clarifications, there may be no need for follow-up interview. The initial interview will take approximately 1 hour and the follow-up interview (if necessary) will take approximately 30 minutes.

I will use a small digital audio voice recorder to record during both interviews and I will be taking notes during the interview. Special care will be taken to guarantee the confidentiality of the data collected as part of this study. My advisor, Dr. Richard Hechter (contact information below), and I will be the only people with access to raw audio data, and I will ensure that all identifiers (such as your name and the name of the school) will be omitted or replaced by pseudonyms. Any data will be securely stored in password-protected hard drives or in locked drawers in my house, and only I will have access to it. All data will be destroyed after five years from the conclusion of the projected, estimated to happen in December 2021.

There is minimal risk anticipated in this study. If an unexpected disclosure arises, such as the abuse of students, I am governed and guided by the Manitoba Teachers Society Code of Ethics and by the guidelines and regulations of [NAME OF SCHOOL] and I will report the allegations to the appropriate authorities.

If you indicate that you would like to revise materials produced for dissemination of this research (by signing in the appropriate field below), I will send you any dissemination material for you to review. You will have at least two weeks to provide feedback on these materials; if you find that you do not want your data included in these materials, I will remove this data from these materials.

Participation in this research project is completely voluntary, and you may withdraw from participating at any time, even after having signed the consent form, with no prejudice or consequence. No compensation will be provided to participants. There are no direct benefits to participants, but they may be interested in learning more about this topic through the opportunity to review pre-print and summaries of dissemination materials.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participation as a subject. In no way does this waive your legal rights nor release the researcher from their legal and professional responsibilities. You are free to withdraw from participation in this study at any time, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Nursing and Education Research Ethics Committee. I am available to meet with you in person to explain the research in more details or answer any questions or concerns you may have regarding this study. You can contact me through phone number and/or email address provided above. You may also contact my advisor, Dr. Richard Hechter, at the University of Manitoba if you have any questions or concerns regarding this study. His telephone number is 204-474-9013 and his email address is richard.hechter@umanitoba.ca. You may also contact the Human Ethics Coordinator at the University of Manitoba if you have further questions at 204-474-7122 or humanethics@umanitoba.ca.

A copy of this consent form has been given to you to keep for your records and reference.

[Signature] [Date]
Jason Hurton

____
[Participant's Full Name – in print]

_____________________________ ____________________
[Participant's Signature] [Date]

Please send me a summary of the findings of this research to the following email address:

____

Appendix E: ENREB Approval

UNIVERSITY OF MANITOBA | Research Ethics and Compliance

Human Ethics
208-194 Dafoe Road
Winnipeg, MB
Canada R3T 2N2
Phone +204-474-7122
Email: humanethics@umanitoba.ca

PROTOCOL APPROVAL

TO: **Jason Hurton** **(Advisor: Richard Hechter)**
Principal Investigator

FROM: **Joseph Gordon, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2019:034 (HS22838)**
Technology Based Formative Assessment: Student Perceptions in Pre-Calculus Mathematics

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Effective: June 6, 2019 **Expiry:** June 6, 2020

Education/Nursing Research Ethics Board (ENREB) has reviewed and approved the above research. ENREB is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.*

This approval is subject to the following conditions:

1. Approval is granted for the research and purposes described in the application only.
2. Any modification to the research or research materials must be submitted to ENREB for approval before implementation.
3. Any deviations to the research or adverse events must be submitted to ENREB as soon as possible.
4. This approval is valid for one year only and a Renewal Request must be submitted and approved by the above expiry date.
5. A Study Closure form must be submitted to ENREB when the research is complete or terminated.
6. The University of Manitoba may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

Funded Protocols:

- **Please e-mail a copy of this Approval, identifying the related UM Project Number, to the Research Grants Officer at researchgrants@umanitoba.ca**

Research Ethics and Compliance is a part of the Office of the Vice-President (Research and International)
umanitoba.ca/research